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by the Bureau of Flood Control will be published as the first number of the series, the present publication, "FLOOD CONTROL ACTIVITIES IN ASIA AND THE PACIFIC" has been obtained from replies of technical organization member countries of ECAP to a questionnaire addressed on technical documents complementing these replies. entitled "METHODS AND PROBLEMS OF FLOOD CONTROL IN ASIA AND THE PACIFIC" will be published later.

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CONTENTS

	Page —
I. Summary hydrology of Asia and the Far East :	
Temperature, pressure and wind	5
Precipitation and cyclone	6
Run-off and silt flow	8
II. Development of flood control works of the region :	
River alluvium of the region	11
Influence of population pressure on the development of flood control works	12
Physiographical influence on flood control measures	14
Development of flood control methods	15
III. Flood damage and flood control activities of various rivers of the region :	
Brahmaputra River	17
Brantas River	20
Chao Phya River	21
Damodar River	25
Ganges River	29
Hai River	32
Huai River	35
Indus River	38
Irrawaddy River	42
Kelani River	47
Kosi River	49
Mahanadi River	52
Mekong River	58
Pampanga and Agno River	61
Pearl River	64
Red River	68
Solo River	70
Yangtze	72
Yellow River	77

App. I — Summary of basic data of rivers.



LIST OF FIGURES

Figure	Page
1. Index map of Rivers of Asia and the Far East	Front page
2. Rainfall and mean temperature of selected stations in Asia and the Far East	6
3. Surface wind and mean sea level pressure in January	6
4. Surface wind and mean sea level pressure in July	6
5. Extra tropical cyclone tracks	8
6. Tropical cyclone tracks	8
7. Hydrograph of some rivers in Asia and the Far East	9
8. Density of Population in Asia and the Far East Region	13
9. The Brahmaputra and the Ganges River Basin	At the end
10. The Brantas River Basin	"
11. The Chao Phya River Basin and Flooding of the Central Plain	"
12. Damodar River Basin Development Scheme	"
13. The Hai River system and Flood Control Project of the Yung Tung River	"
14. Flood Control Project and Existing dykes of Grand -- Huai Basin	"
15. The Indus River Basin	"
16. The Irrawaddy and Sittang River Basin	"
17. Flood Control Scheme of Kelani Ganga	"
18. Kosi Project	"
19. Mahanadi Valley Development	"
20. River Basin of Mekong and Red River	"
21. The Pampanga and Agno River Basin	"
22. Dykes in the Pearl River Delta	"
23. The Solo River Basin	"
24. Proposed Flood Control Scheme of the Yangtze River Basin	"
25. Yellow River Basin	"
26. Dike systems of rivers in Asia and the Far East Region	"

CHAPTER I

SUMMARY HYDROLOGY OF ASIA AND THE FAR EAST

The area, known as Asia and the Far East, extending from the Sunda Islands, south of the equator, to Manchuria and Korea in the north, embraces a wide variety of climatic features ranging from tropical rainy to snow cool. The Sunda Islands, Malay Peninsula and Borneo, lying in the equatorial region within the doldrum zone, experience slight annual variation of temperature and moderate to heavy precipitation during every month of the year. Cooling of the vast land mass of the continent of Asia with its high range of mountain barriers in the south during winter, and intensive heating during summer, give rise to the characteristic climate of this area—winter and summer monsoons. Winter is essentially a dry season, and summer a very rainy period in the vast area that comprises South-East Asia. Rivers of the Asian continent swell during the rainy season, but high floods are the result of increased precipitation following the formation of cyclones, either depressions of hurricanes, developed during the summer monsoon period and travelling across land.

TEMPERATURE, PRESSURE AND WIND (1)

Temperature.

The distribution of temperature over the region varies in general with the latitude and is modified by the land mass of the continent. Isotherms as a

general rule run east-west and roughly follow parallel latitudes, but bend poleward over the continent during the winter season due to the accumulation of a cool, dry air mass over the continent. The annual range of temperature is slight along the equator and increases with the latitude northward.

The temperature of the islands along the equator is quite constant throughout the year. The mean annual temperature of Djakarta is 26.2°C, with an annual range (difference between average temperature of warmest and coldest months) of only 1.1°C. Further north in India, Burma and Thailand, the monsoon type of temperature prevails. Here the highest temperature is reached in May, before the beginning of the south-west monsoonal rains, which are characterized by greater cloudiness and precipitation with the convection of maritime air, and which thus terminates the normal temperature rise. For example, in this region, the mean annual temperature in Calcutta is 25.6°C with an annual range of 11.3°C.

From the monsoonal type of this area, the temperatures change toward the north into the continental type with a transition of temperate zone. On account of the vastness of the land area, the continental type of temperature prevails in Central and North China with the maximum in July and minimum in January. The temperature curve is essentially symmetrical with respect to maximum and minimum. As the vast area is covered by a mass of cold air of the well-developed anti-cyclone of Siberia, the temperature is low in winter. In Peking, the mean annual temperature is 12°C with an annual range of 31.1°C.

Pressure and Wind

The difference in temperature in various part of the region produces a difference of pressure which induces air motion. Along the equator in this region,

(1) B. Haurwitz and J. M. Austin, *Climatology* 1945 (New York, McGraw Hill Book Co., 1945); Chung-Yih Shih, *Some Remarks on Climate of the Far East*, 1949 (typewritten copy); W. G. Kendrew, *The Climates of the Continent*, 1932 (New York, Oxford University Press); Weather Division, Headquarters, Army Air Force, U.S.A. *Weather and Climate of China*, 1945; Fig. 2, 3, 4, 5 are reproduced from B. Haurwitz and J. M. Austin with permission from the publisher, McGraw Hill Book Company.

a belt of moderately low pressure, which is fairly well defined throughout the year, becomes irregular in summer as a result of the centre of low pressure lying over the heated interior of the Asian continent. The equatorial belt is a region of warm and rising air and of light and variable winds with frequent calms. This condition is most pronounced in the area of the doldrums — the narrow central area of the belt between the winds from the Northern and Southern hemispheres. This doldrum area lies between latitudes 5° to 10° N and 5° to 10° S, but most of it is a little north of the equator.

The pressure and wind distribution of the Asian continent is greatly influenced by the land mass and the topographical features. The Himalayas and the very high plateau of Tibet in the south and west protect the continent from the invasion of the maritime air mass in winter. Owing to the vastness of the continent, cold and dry air masses accumulate during winter over the interior, and the winter anti-cyclone is well developed with the central pressure located some 50° north of the equator. Around the equatorial trough is a low pressure belt. The circulation around the anti-cyclone dominates the air flow. The prevailing wind is north-westerly over Central and North China. When across Indochina, Thailand and South India, the prevailing wind becomes north-easterly. This is known as the north-east winter monsoon. In the Philippine and Sunda Islands, north of the equator, the wind remains north-easterly on account of the low pressure area which has developed around North Australia due to the continental heating. As a consequence of the air motion across the equator, the north-east winds become north-west in the southern hemisphere.

While the continental anti-cyclone dominates winter circulation over Asia, summer circulation is primarily controlled by a vast thermal low pressure belt centred about 30° north of the equator, produced by intense heating of the continent of Asia. A tropical high pressure belt exists in the Indian Ocean south of the equator. Following the pressure gradient, the south-east trade wind of the southern hemisphere becomes the South-West monsoon after crossing the equator and sweeps over India, Burma, Thailand and the southern part of Indochina. In China and the Philippines, however, the continental low and Pacific high induce the formation of the South-East Monsoon.

PRECIPITATION AND CYCLONE (1)

Precipitation.

Since precipitation is primarily produced by cooling due to the adiabatic ascent of moist air masses,

the principal zone of precipitation of the region is near the equator where the normal trade winds converge into the zone of doldrums. This zone covers a belt 5° to 10° north and south of the equator including the Sunda Islands, Borneo and the southern part of the Malay Peninsula.

In its broadest sense precipitation occurs every month throughout the year and the variation follows the meridional displacement of the doldrum low-pressure belt. The area north of 5° North, which includes the southern part of the Malay Peninsula, north Sumatra and the northern half of Borneo, receives most rain from June to October, and least from December to April; while in the area south of 5° South, which includes south Borneo and Java, June to October is the period of least rainfall with the maximum occurring from December to April. Even though dry and wet seasons may be distinguished, there is no month without appreciable rainfall. Near the equator rain falls approximately uniformly throughout the year.

Variations noticed in different locations are due principally to local causes such as the orientation of

lifting. For example, in the northern hemisphere during the period of the North-East Monsoon, precipitation is heavier along the east coast than along the west coast. The general heavy precipitation is caused by high moisture content and the instability of maritime tropical air masses over the warm ocean. Convective instability results in a large number of thunderstorms. They are probably more frequent here than in any other region. Very heavy rain showers are common features of regions of orographic lifting and weak tropical cyclones. The convective showers are produced either by convergence toward the equatorial low pressure belt, or by diurnal heating over land. The average annual precipitation of this region is around 2,500 mm.

Further north in India, Burma, Thailand and South Viet-Nam, the rainfall is primarily controlled by the monsoons with marked dry winters and wet summers. During the North-East Monsoon of winter, the Himalaya range and the high plateau of Tibet prevent the direct outbreak of cold continental polar air masses across South-east Asia and India. The continental polar air mass, which modifies during the downslope movement, upon reaching the southern plains becomes mild and dry air currents. As a combined result of this, and off shore circulation, this area has a low winter precipitation. However, during the cold period of the year some of the more intense Mediterranean cyclones coming over Persia and Afghanistan move across the north-west of India and produce some precipitation in India. In Indochina the east or north-east winds on the Central Viet-Nam coast, during winter, are moisture laden after having crossed the ocean. Heavy precipitation, due to orographic lifting, results along the east coast during the early winter months.

(1) See footnote p. 5.

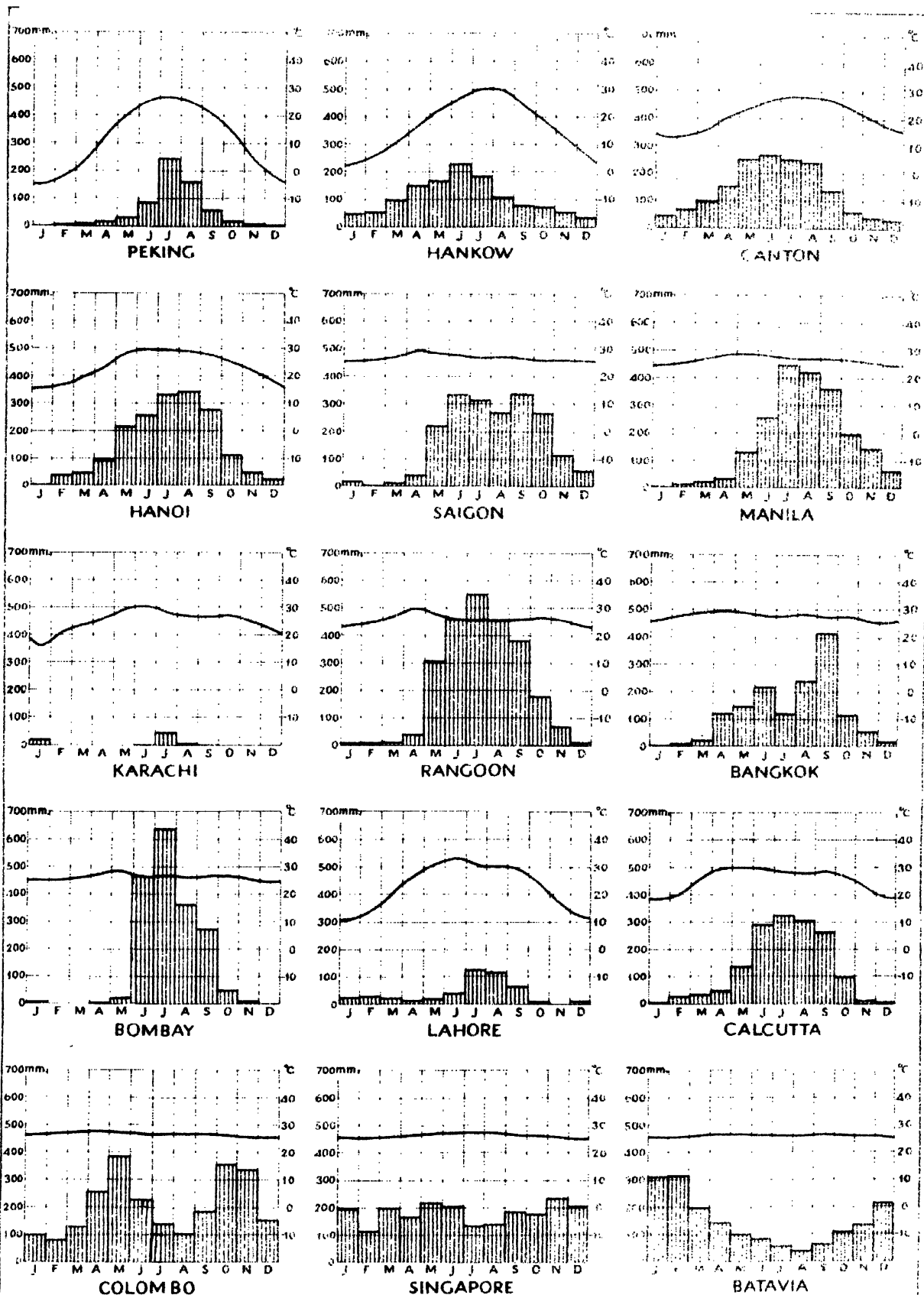


FIG. 2 RAINFALL AND MEAN TEMPERATURE OF SELECTED STATIONS IN AFE REGION
 PLUVIOMETRIE ET TEMPERATURE MOYENNE DE DIVERSES STATIONS DANS LA REGION

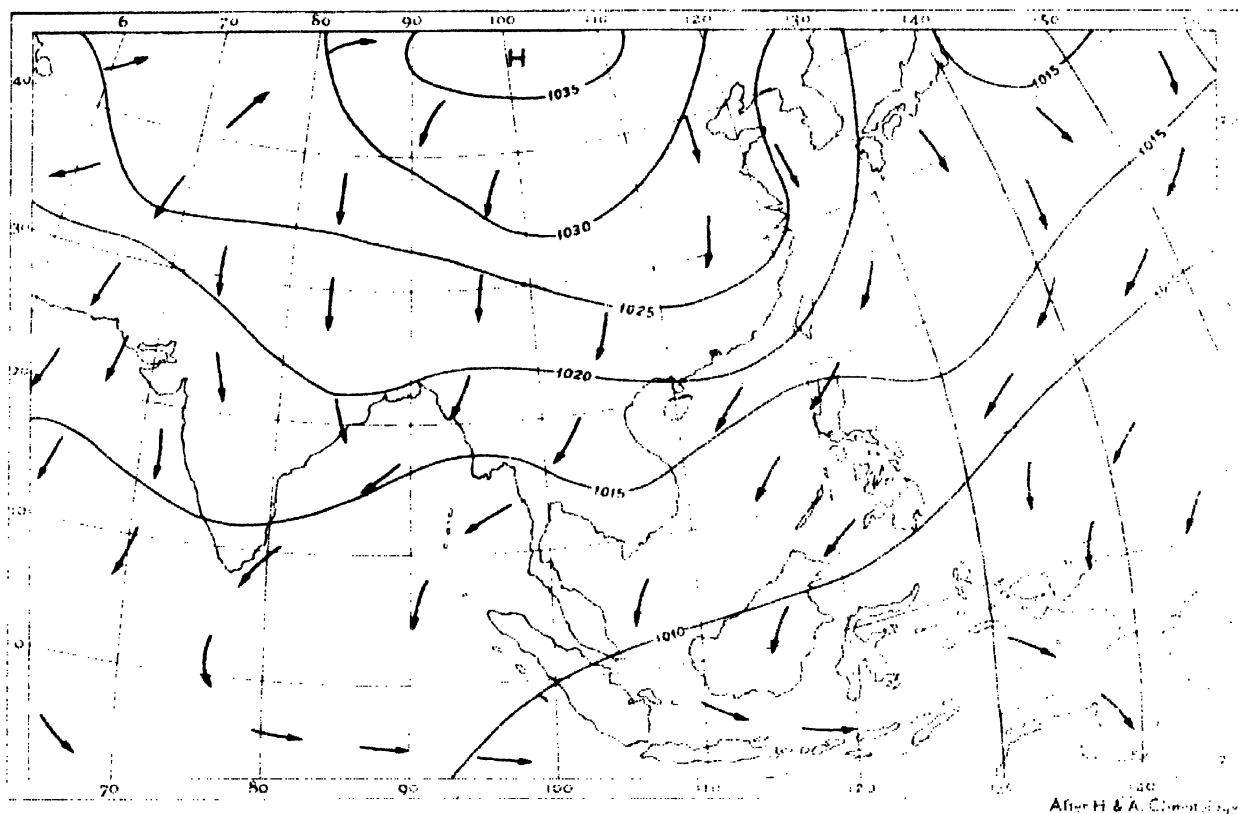


FIG. 3 SURFACE WIND AND MEAN SEA LEVEL PRESSURE IN JANUARY (MILLIBARS)
VENT AU SOL ET PRESSION BAROMETRIQUE (RAMENEE AU NIVEAU DE LA MER) MOYENNE EN JANVIER

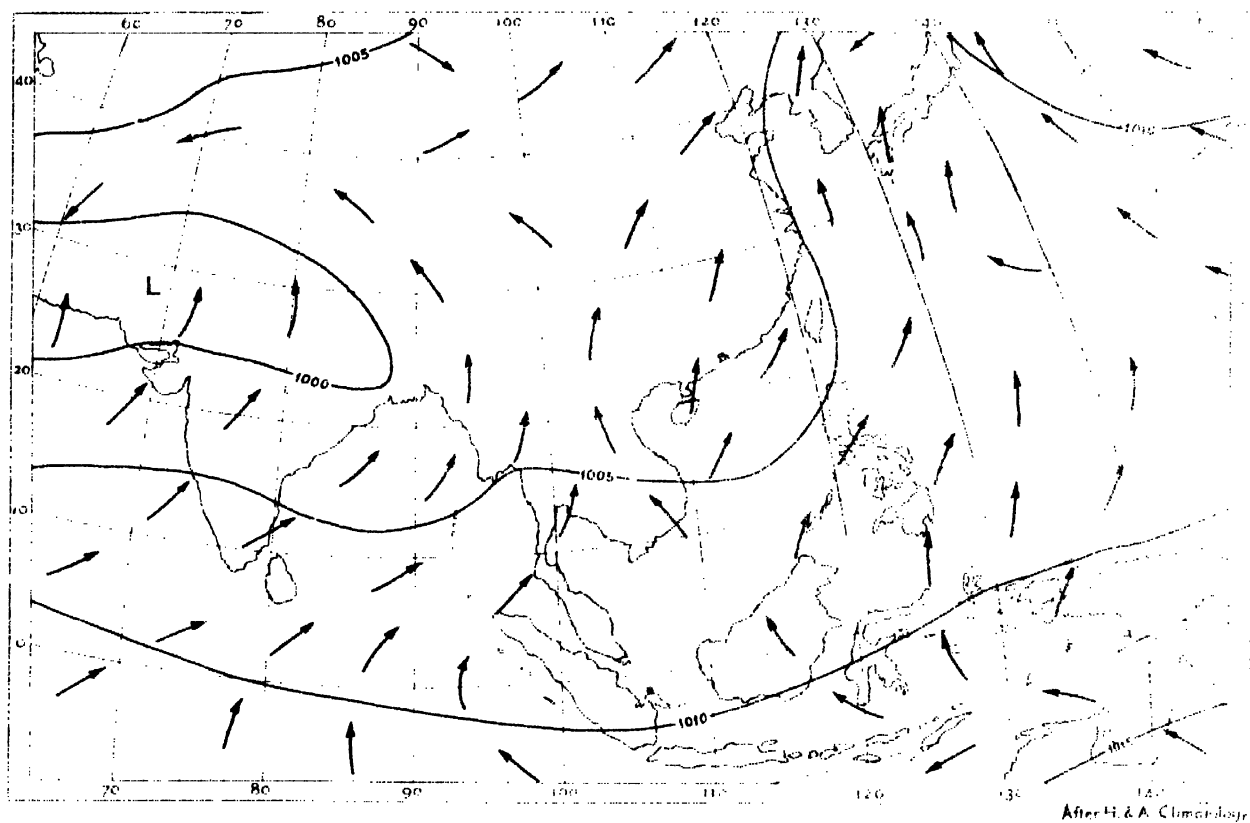


FIG. 4 SURFACE WIND AND MEAN SEA LEVEL PRESSURE IN JULY (MILLIBARS)
VENT AU SOL ET PRESSION BAROMETRIQUE (RAMENEE AU NIVEAU DE LA MER) MOYENNE EN JUILLET

With the approach of summer, a high pressure belt is developed south of the equator and a low pressure belt over the continent. The favourable gradient is conducive to the setting in of the South-West summer monsoon, which starts generally from mid-June. The presence of this warm, moist and convectively unstable air mass results in a period of general rains over India, Burma, Thailand and south Indochina. Orographic lifting favours quite heavy precipitation along the Western Ghats of India, the southern slopes of the Himalayas, Burma and the western ridge of the Malay Peninsula. In West Pakistan, however, west of the Indus-Ganges divide and the desert of Sind, the dominating dry air descending from the north-west across the arid plateau of Afghanistan and Baluchistan, can yield no rain during this season. In general, the summer monsoon covers a period roughly from June to September and furnishes the major portion of the annual precipitation which feeds the flow of the rivers. Floods in this area, however, are caused by intensified precipitation in the monsoon season following tropical cyclones. This will be discussed in a separate section later.

The Philippine Islands, with a topography of low plains and mountains surrounded by sea, receive precipitation from both the South-West and North-East monsoons. The South-West monsoon of summer brings rain on the western slope of mountains with a maximum precipitation from July to September, while during the prevalence of the North-East monsoon in winter, the eastern slopes receive appreciable rainfall. Frequent rains in the Philippines may be credited also to the pronounced easterly waves which often times give rise to a closed circulation attaining typhoon intensity. Typhoons causing floods travel across these islands during the months of July to December. They are most frequent in July.

In China, the prevailing high pressure belt developed in the continent during winter gives rise to extremely scanty precipitation in the north, while an appreciable amount occurs in the south due to frequent winter cyclones. Along the coast, slight but frequent rainfall is associated with the north-east monsoonal drift.

With the advance of summer, heavy frontal precipitation occurs when the tropical air mass from over the ocean overruns the slow retreating polar mass of the continent. These frontal pulsatory rains are called Mai-U. In May, the average position of the frontal zone is in south Central China. It advances gradually northward and reaches the Yangtze valley in June. The Mai-U rain, when augmented by the developing extra-tropical cyclone moving eastward, gives the heaviest precipitation particularly in the Yangtze valley. Toward the north the Mai-U rainy season gradually shortens. In North China, heat convection, weak frontal lifting and convergence within occasional cyclones, are the principal causes of summer precipitation. Again heavy precipitation causing floods is

due to the cyclonic disturbances developed in association with the moist maritime air mass of summer.

Cyclones ⁽¹⁾

The cyclones that develop in the region of Asia and the Far East comprise two types — extra tropical and tropical. The general track of the extra tropical cyclone is from west to east. In winter, an extra tropical cyclone of Mediterranean origin moving across north India gives rise to winter precipitation (type 9, figure 5). The occurrence of extra-tropical cyclones in other parts of the region is rare, except in Central China, where it is more frequent in summer than in winter. In the Yellow River basin, extra-tropical cyclones develop along the front of the indrawn moist maritime air mass, and the continental air mass. Accompanied by heavy precipitation the cyclones move slowly east or north-eastwards (type 12 B, fig. 5) spreading over the middle and lower valley and account for the floods. In the Yangtze Valley, particularly during the Mai-U season of early summer, cyclones develop on the front when the tropical maritime air mass overruns the retreating polar continental air mass resulting in the heaviest rain (type 9 A, Fig. 5). The front tends to be stationary if there is an unusually pronounced and lasting winter high over Siberia and Mongolia. Such was the case in July 1931 when the greatest flood in the Yangtze valley known since the beginning of hydrological observations occurred. The number of Yangtze cyclones was six. The monthly rainfall at many stations, particularly those north of the path of the cyclones, amounted to 600 to 700 mm., which was about 350 per cent of the normal monthly average. The flood flow of the Yangtze corresponded to a frequency of once in a hundred years and, as a consequence, 23 million people suffered in a flooded area covering 250,000 sq. km.

Cyclones of tropical origin occur more frequently in Asia than in any other part of the world, particularly in the China Sea region. The tropical cyclones generally originate on the ocean south of latitude 20°N. They move westward and later turn north or north-east. Most of the Pacific cyclones which later affect the Philippines and South China appear in the region limited by the meridians 126° and 145° East and latitude 5° and 17° North. When they reach or cross the Philippine area their direction is generally from the eastern to the western quadrant. This region is characterized by pronounced instability as a result of the invading tropical air masses from the Indian Ocean (the South-West monsoon) and north and south Pacific Ocean.

Cyclones developing in this area have general tracks as indicated in figure 6. Of those having a

(1) B. Haurwitz and J. M. Austin, *Climatology* 1945 (New York, McGraw Hill Book Co.).

parabolic path, swinging to the north, type 9, which occurs during the summer months from June to September, is responsible for flood flows of the Luzon rivers when they sweep across the Philippine Islands. Storms of type 10 move into the South China area during July and August and cause heavy precipitation in the Pearl River basin. The recent floods of the Pearl River in 1947 and 1949 resulted from the combined effect of typhoons and the summer monsoon.

The Pacific cyclones (typhoons) which move westward across Indochina and Burma, then redevelop over the Bay of Bengal, and continue to move westward over India, are observed during periods of well-established east winds prevailing in the upper air from July to October (type 3, 4). Of the parts of these cyclones striking the coast of southern China or the Indochinese peninsula, a little less than 40 per cent finally progress westward over India. In 1942 (1), two typhoons in quick succession crossed over north Thailand between latitude 15°N. and 18°N. from 4 to 15 September, and gave rise to the excessive flow of the Chao-Phya River which flooded Bangkok. This flood was of a frequency of once in 100 years. The precipitation at Utaradit as a result of these successive typhoons, was 215 mm.

In the Bay of Bengal, besides those coming from the China Sea, cyclones usually develop over the southern section of the Bay, following, in general, the path toward the north, while some move in a westerly direction (type 5, 6). Maximum frequency of occurrence takes place as the summer monsoon retreats while the air masses are unstable. The heavy precipitation of this tropical disturbance during the South-West monsoon season contributes to the flood flow of the rivers of the Ganges system, as well as of others.

The cyclone of October 1942, with a depression developed in the Bay of Bengal, moved into Bengal on 19 October and struck the western districts of the province. All the rivers in Mindnapore, twenty-four Parganas districts and Balasore were in heavy flood. Tidal waves, reinforced by heavy rain, pushed up the water in the northern reaches and caused extensive flooding. Three thousand two hundred square miles were affected by the cyclone, with a complete loss of standing Aman crops, the failure of which was the primary cause of the 1942 famine in Bengal.

Summarizing, the precipitation over the region of Asia and the Far East, islands along the equatorial belt receive precipitation throughout the year. Precipitation over the continent is of a monsoonal nature with heaviest occurrence during the summer monsoon. Extraordinarily heavy rainfall, resulting in floods, is caused by cyclones developed during the monsoon seasons.

RUN-OFF AND SILT FLOW

Run-off

The fluctuations in the stream flow of rivers of the region follows, in general, the same pattern as the seasonal distribution of rainfall, except in the case of rivers originating from the southern slope of the Himalayan range, with considerable drainage areas covered by glaciers and snow, where the streams are fed by melting of the former during the hot season. Depending as it does on the seasonal distribution of rainfall, the run-off of rivers is modified by surface storage (lakes, channel storage), sub-surface storage (infiltration and ground water storage) and evapo-transpiration losses.

The general characteristics of hydrographs of rivers in the continent of Asia, north of the equator, show generally a period of low water flow from January to May. The river flow is mainly supplied by the ground water storage in the form of seepage during this period. A gradual decrease in the water level and discharge during the low water period from January to April is also observed for many major rivers such as the Mekong and the Ganges. Beginning in the latter part of May and June, river flow increases with the advance of the wet season. The maximum flow is reached from July to September. From October till the end of the year water levels and river flows gradually decrease to the low water mark. Rivers with large drainage areas, which receive more or less continuous rainfall during the wet season such as the Yangtze, Mekong and Ganges, show a uniform increase and decrease of river flow during the high water period. On the other hand, the Yellow River and rivers of North China, which receive their flood flow from local convective storms and occasional cyclones, and other rivers such as the Mahanadi and Damodar, which have smaller drainage areas and are not able to equalize the flow owing to intensive precipitation, show marked fluctuations of water level during the high water period.

The flow of rivers in the Philippine Islands and Taiwan (Formosa) is markedly influenced by typhoons. Because of the relatively small drainage areas of these rivers and their steep gradients, a sudden rise and fall of river stage, after the passing of each typhoon, is very noticeable. Rivers of the islands south of the equator, such as Java, have their high water period from January to May, and low water period from August to the beginning of November. A rather sharp rise from low to high water level and a gradual decrease from high water level to low water level is noticeable. The percentage of run-off to precipitation of rivers in the region varies from 73 for the Red River to 12.8 % for the Yellow. The unit mean discharge per square kilometre of drainage area seems to decrease from south to north such as 0.041 c.m.s./sq. km. for the Marangin River

(1) Information supplied by the River Stages and Floods Division, Meteorological Department, Royal Thai Navy.

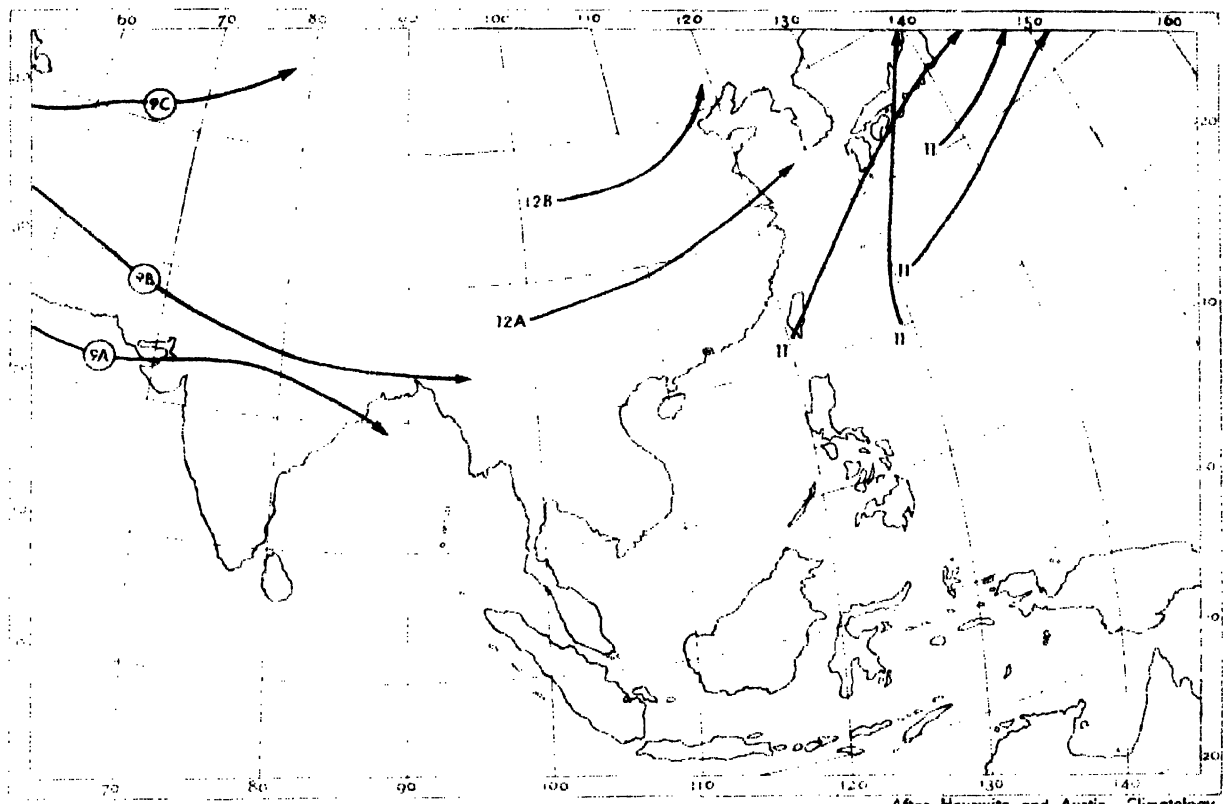


FIG 5 EXTRATROPICAL CYCLONE TRACKS

TRAJECTOIRES DES CYCLONES EXTRA-TROPICAUX

After Haurwitz and Austin, Climatology
Except Track No. 12B After
Hsieh, Lu and Yeh, Hydrology of the Yellow River

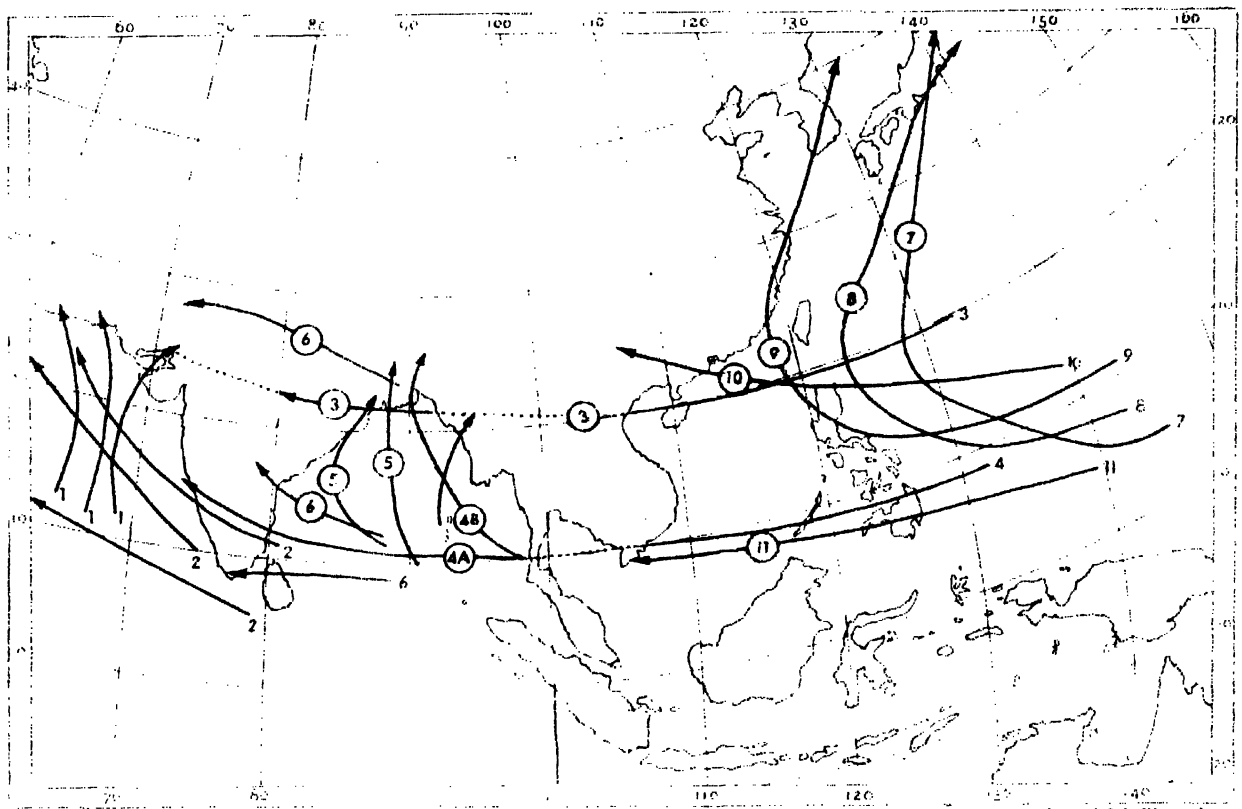


FIG 6 TROPICAL CYCLONE TRACKS

TRAJECTOIRES DES CYCLONES TROPICAUX

After H. & A. Climatology

(Sumatra), 0.0216 c.m.s./sq. km. for the Mahanadi River, 0.0159 c.m.s./sq. km. for the Yangtze River and 0.0019 c.m.s./sq. km. for the Yellow River. The decrease of unit run-off from south to north coincides with the decrease of precipitation in the same direction, but the rate of decrease of unit discharge and run-off coefficient exceeds that of precipitation. This can be explained by the increase of evaporation in the relatively more arid continent towards the north.

The flood discharge depends on the amount of

precipitation and the size of the drainage area. Of all the rivers of this region, the Yangtze gives the maximum recorded-flood flow of 80,180 c.m.s. (2,840,000 c.f.s.). The Ganges, with a drainage area approximately half that of the Yangtze, has a recorded maximum of 60,200 c.m.s. (2,125,000 c.f.s.). A comparison of flood discharge per unit drainage area shows an increase from north to south as a consequence of increasing rainfall intensity. Rivers with smaller drainage basins give a relatively higher rate.

Unit Discharge of Rivers

NAME OF RIVER	STATION	DRAINAGE	RAINFALL	%	UNIT	UNIT	RATIO OF	UNIT SILT
		AREA	IN		MEAN Q (a)	MAX. Q.		
		SQ. KM.	MM.	RUN-OFF	C. M. S. PER SQ. KM.	C. M. S. PER SQ. KM.	MAX. Q. TO MIN. Q.	TONS PER SQ. KM.
Chao-Phya .	Wadthahad	112,000	1,180	25	.0315	.058	100.0	—
Damodar . .	Rhondia	9,900	1,180	42.5	.0158	.92	—	1,420
Ganges	Faracca	905,000			.0155	.067	34.6	—
		(whole basin)						
Huai	Fushan	147,360	770	17.4	.00345	.105	750	—
Irrawaddy .	Saiktha	367,000	1,750	66.0	.037	.156	48.8	702
Kosi	Chatra	61,668	1,790	55.1	.0316	.438	97.7	2,820
Mahanadi .	Naraj	132,000	1,380	49.6	.0216	.364	1080	465
Murangin . .	Sumatra	3,960			.041	.782	—	—
Mekong	Kratié	662,000	1,500	54.8	.024	.0905	35.3	151
Pearl (West. R) .	Wuchow	313,000	1,530	51.3	.0254	.229	74.7	89
Red River . .	Vietri	113,000	1,500	73.0	—	.31	50	1,150
Yangtze . . .	Chihkiang	1,025,000	800	63.0	.0159	.0731	22.1	491
Yellow	Shenhsien	715,184	470	12.8	.0019	.0349	102	2,640

Source : Bureau of Flood Control, ECAFE, Replies to Questionnaire on Flood Control.

(a) Q indicates discharge.

An examination of the details of run-off of some of the major rivers of the region (see figure 7) shows that the Yellow River, though possessing a large drainage area, is characterized in its hydrographs by the absence of any pronounced duration of mean water flow. Rainfall due to storms and cyclones on the bare loessial area, which is without surface cover and lies immediately above the great alluvial plain, results in a distinct and sharp fluctuation of flood flow and a heavy silt load over only a few days during every storm. Both the flood peak (25,000 c.m.s. or 883,000 c.f.s.) and flood volume (3,200 million cu.m. or 2.6 million ac.ft.) are not comparable with those of other large rivers of the region. It is interesting to note the effect of channel storage on the peak discharge of flood flow ; above the vast fore-shore area between the dikes it amounts to 7,970 million cu.m. (6.5 million ac.ft.) over a total distance of 703.5 km. (439 mi.). The flood peak is reduced to less than half its original value when it discharges into the sea.

Characteristic of the hydrograph of the Yangtze is the extreme fluctuation of its water level in, and

above, the gorge section upstream of the plain, and the moderating effect of Tungting Lake on the lower course of the river. Due to the huge volume of the flood flow and the backwater effect of the long gorge section, the fluctuation of water levels for low and high water above the Yangtze Gorge at Wanhhsien reaches 42.35 m. (138 ft.), and the maximum rise of stage is 10 m. (33 ft.) a day.

The hydrograph of the lower Mekong is noteworthy for the regularity of its rising stage and duration from June to October, and the period of receding from October to January, which are almost the same every year. The flood flow is greatly influenced by the Tonle Sap which acts as a huge reservoir. The area of the lake increases from 3,000 to 10,000 sq. km. (1,160 to 3,860 sq. mi.) and its depth from 1 to 10 m. (3.3 to 33 ft.) during the flood season. The increase in volume is approximately 35,000 million cu.m. (28.5 million ac. ft.) and this flattens the flood flow of the lower course of the river.

Rivers of comparatively smaller drainage areas such as the Damodar 22,000 sq. km. (8,500 sq. mi.) and Mahanadi 132,000 sq. km. (51,000 sq. mi.) show

Silt Flow (2)

in their hydrographs the characteristics of torrential streams with very low flow during the dry season of the North-East monsoon, and the sudden rise and fall due to very heavy precipitation caused by storms and depressions.

The Ganges River system, with a drainage area of 905,000 sq. km. (350,000 sq. mi.) and its many tributaries, shows a gradual increase from May to September, and a decrease from October to April.

Glaciers (1) and snow play an important part in the run-off of the rivers rising from the southern slopes of the Himalayan range such as the Indus, Chenab, Sutlej, Jumna and Tons, a considerable part of whose drainage area is covered by glaciers and snow. The snow line of the perpetual snows of the Assam Himalayas is at an altitude of 4,420 m. (14,500 ft.). In the north the snow line varies between 5,180 m. and 5,800 m. (17,000 to 19,000 ft.). The glaciers of the Kashmir hills descend to a much lower limit of 2,440 m. (8,000 ft.). It would appear that glaciers in general, all over the world, are at present in a state of recession. Based on a 20-year record from 1923 to 1942, the run-off coefficient of the Chenab River at Marala equalled 102 per cent for the annual mean rainfall and 283 per cent for the hottest month of the year in June. This is due to the melting of glaciers and snow covering 13 per cent, or 1,475 sq. km. (570 sq. mi.) of the total drainage area, excluding the areas dominated by seasonal snow. The coefficient of run-off also varies from year to year. The maximum annual was 122 per cent for 1934, while the maximum monthly was recorded at 1429 per cent in May 1938. The contribution of glaciers to the Tons, which has a glacial area of 264 sq. km. (102 sq. mi.), varies from .055 to .426 c.m.s. per sq. km. (5 to 39 c.f.s. per sq. mi.) and to the Jumna system, taken as a whole, which has a combined glacial area including that of the Tons of 344 sq. km. (133 sq. mi.), varies from .066 to 0.404 c.m.s. per sq. km. (6 to 37 c.f.s. per sq. mi.). The run-off, as a general rule, exceeds the precipitation from May to October.

The silt flow of rivers of the region has long engaged the attention of hydraulic engineers. As silt in suspension is the result of soil erosion caused by heavy rainfall, or continuous rainfall over long periods, the silt content of the flow of rivers varies directly with the discharge of river flow, but the maximum silt content usually occurs some time after the maximum flood peak. Except for the Yellow River, North China rivers and the Kosi River, the maximum silt content of the major rivers of the region (not of the small tributaries) does not exceed one per cent by weight, and the mean annual figure is below three per thousand. The Yellow and North China rivers, whose drainage area is mainly composed of highly erodible loess, which covers the bed rock to a depth of around 50 m. (160 ft.) and is a unique phenomenon in itself, have a silt content, during floods, as high as 46 per cent by weight (weight of dry silt per unit weight of suspension). The flood flow has the appearance of a muddy paste, rather than that of an ordinary fluid. The total silt run-off of the Yellow River is highest among all the rivers of the region, and reaches an annual figure of 1,890 million tons. The Yangtze River, the largest river of the region, has an annual silt run-off of 967 million tons, while that of the Kosi River is 174 million tons. Regarding the specific silt run-off per unit drainage area of rivers of the region, taking the total drainage area as the basis of calculation, the Kosi River shows the highest unit silt run-off of 2,820 tons per sq. km., while that of the Yellow River is 2,640 tons per sq. km. Since the silt run-off of the Yellow River mainly originates from the loessial area, which is approximately 37.4 per cent of the whole basin, the specific silt run-off, when calculated on the basis of the loessial area, gives the highest value of 6,800 tons per sq. km. The annual erosion over the 288,234 sq. km. loessial area of the Yellow River basin is 4.25 mm.

Solid material carried by stream flow is either in suspension or in bed load. No data is available for the transportation of bed loads of rivers of the region.

(1) Kanwar Sain *The Role of Glaciers and Snow on Hydrology of Punjab Rivers*, 1946 (Central Board of Irrigation Publication No. 36, (India).

(2) Bureau of Flood Control, ECAFE, *Silt Problem*, E/CN. 11/FLOOD/L. 2, 1950 (Bangkok, ECAFE) pp. 9-10.

CHAPTER II

DEVELOPMENT OF FLOOD CONTROL WORKS IN THE REGION

RIVER ALLUVIUM OF THE REGION

The predominance of agricultural activity in the Asian economy is an accepted fact. Of Asia's great population, 89 per cent of the gainfully employed population of Thailand, 73 per cent of that of Korea, 70 per cent of that of Burma, 69 per cent of that of the Philippines and 67 per cent of that of India is engaged in agricultural production ⁽¹⁾.

The alluvium of river valleys and river deltas provides the most suitable area for agriculture. River alluvium is particularly fertile. The flat topography of these areas lends itself admirably to farming. River alluvium is adjacent to the stream, and the river delta is criss-crossed by numerous creeks which facilitate irrigation and the transportation of food grains. Practically all the ancient cities of any size or importance have been built along the banks of the major rivers. Rice, the staple food of the majority of Asia's peoples, is cultivated preponderantly in the river valleys and deltas. Ninety-four per cent of the total cultivated area of Thailand, 83 per cent of that of Indochina and 77 per cent of that of Burma is under rice cultivation. The importance of river alluvium to the region is shown by the population density. The AFE region, with an area of 19,032,000 sq. km. and a population of 1,142,332,000 in 1947 ⁽²⁾, has an average density of 60 persons per sq. km. The river alluvium of the great streams of the region is, however, far more densely populated. For example, in the deltas of the Red River and the Pearl River the density reaches 500 and 1,056 per sq. km. respectively ⁽³⁾.

The fertile river alluvium is the result of deposition by floods. Heavy or moderate, but continuous, rainfall erodes the surface soil in the headwaters of a river basin, and the flood flow carries the eroded soil in suspension. In the upper valley of a river basin where a river cuts perpendicularly through a mountainous ridge such as a gorge, the retardation of flow due to back water effect causes depositions on the broad valley upstream of the gorge. In the course of time, the incision of the gorge section lowers the water level, and strips and sometimes small plains of river alluvium are left above the gorge section in the upper valley. These are later affected only by extraordinary floods. Such strips or plains of river alluvium can be found in the head water areas of rivers of this region. The trenching of a river valley, along the lower course of the stream, generally tends to be lateral. The foots of hills in the river valley are eroded as the stream pursues a meandering course. When the silt-laden flood flow is spread over a broadened valley, deposition occurs and raises the land along one, or both, sides of the river. A strip of river alluvium is thus formed which is a common feature of many lower courses of rivers.

Of greatest importance, however, is the formation of the vast alluvial plains along the sea coasts where the rivers enter the sea. Silt in suspension carried down by the rivers settles down in the sea in the depressions immediately in front of the river mouths. At first lagoons or swamps appear, and then through continuous deposition of solid particles they are filled and the land is elevated. As the shore line gradually extends seawards, lands lying behind must rise correspondingly, if the required slope for river flow is to be maintained. Seasonal inundations of lands by the rivers provide the necessary building up. During low water or floods of smaller magnitude, the river cuts through the alluvium forming a more or less definite channel. The spilling over banks occurs only during the flood season when a larger flow can be expected.

(1) United Nations : Economic Survey of Asia and the Far East, 1948, p. 3.

(2) *Ibid.*, p. 13.

(3) Bureau of Flood Control, *Replies to Questionnaire on Flood Control*.

Large tracts of land, stretching from the hills to the sea, with gradually diminishing slopes, are formed in this way. The spreading of the flow and the deposition of silt over the alluvial plain is by no means uniform over the whole area. The magnitude of flood discharge and the quantity of suspended matter varies from year to year. If deposition takes place at certain locations and raises the ground level, successive floods will tend to raise the low-lying areas.

In general, low-lying areas near the sea are subject to frequent flooding. Those behind, which have been built up sufficiently high, are subject to overflow only during floods of greater magnitude, which occur less frequently. The process of building up river alluvium, and the rate at which this is carried out depends on the silt load and the topography. A heavy silt load and shallow sea aid the rapid formation of alluvium. A typical case is that of the Yellow River. This river carries annually a silt load of 1,890 million tons, and flows into the shallow Gulf of Po Hai which has a depth of only 20 m. at a distance of 60 km. from the coast, or sea bottom slope of 1 : 3,000. Measured along the river course today, the shore line in 5,500 B. C. was 500 km. landward away from its present position. The vast alluvial tract which exists now is a gigantic cone-shaped deposition with its apex situated at the exit of the gorge above Mengtsin. This is also true of the vast alluvial tract of the Kosi River after its debouch from the Himalayan range on the great Gangetic Plain. In spite of the comparatively less silt in suspension carried down by the Yangtze River, the numerous lakes and depressions that dot its lower course indicate that the process of alluvium formation is still continuing, though curtailed by the present dike system. Further striking examples are the great alluvial Central Plain of the Chao Phya River in Thailand, and the large plain of the lower course of the Mekong in Cambodia and South Viet-Nam, which are subject to annual flooding during the high water season.

Since alluvium is continuously in the process of formation, it is always subject to flooding. Based on the magnitude and frequency of flood flow and the "age" of the plains, some "young" ones are subject to annual flooding while others are overflowed by rivers only on rare occasions.

INFLUENCE OF POPULATION PRESSURE ON THE DEVELOPMENT OF FLOOD CONTROL WORKS

Soil and moisture are basic necessities for plant growth. The rich soil of river alluvium is best suited to agriculture. Since, as a general rule in the region, the monsoon season, when sufficient rainfall is available for plant growth, coincides with the flood period,

the cultivators in the alluvial plains of the rivers have to face the flood problem. Tracing the development of protection of crops from floods in the region, the following methods have been adopted at one time or another :

- a) Adapting crops to flood conditions.
- b) Finding crops which will grow outside the flood season.
- c) Protecting crops by dikes.

Reviewing in general the methods employed, apart from differences in topography, flood season, tradition etc., it would appear that fundamentally the adoption of any particular method of flood control is linked with the problem of population.

In Indonesia, although large rivers flow in the big islands such as New Guinea, Borneo and Sumatra, protection against floods in these islands has been little developed because of the very low density of population. There are still in these islands large areas of floodfree, arable land for the extension of cultivation. In Java, however, the population has increased so much that it has become imperative for every inch of arable land to be cultivated in order to provide sufficient food for the people. Here dikes are constructed along the banks of many rivers such the Solo and the Brantas.

The selection of a particular method of flood control, therefore, is governed by the necessity to ensure that the yield from available land under a certain practice of cropping will be sufficient to feed the population. The construction of dikes against floods so as to ensure the highest possible yield during the growing season has been, and is, certainly governed by the pressure of population. The question of whether the cost of construction and annual maintenance of dikes is balanced by the increase in crop yield has to be answered in individual cases.

The practice of adaptation of crops to suit flood conditions can best be illustrated in the Central Plain of Thailand, and the lower plain of the Mekong in south Indochina.

The Chao Phya river throws out many branches as it flows into the Central Plain. As is common to a stream having an overflow, a strip of higher land exists along both banks of the river and its effluents. The land surface gradually slopes away from the river thus forming a depression between its branches. Flood flow spills over the banks along the effluents as well as the Chao Phya river annually. Vast sheets of water spread over and submerge the entire Central Plain to the extent of 15,700 sq. km. (see Fig. 11). Aside from the depressions the average depth of inundation during ordinary annual floods is 0.3 to 1.5 m. (1 to 5 ft.) and the depth of water in the depressions varies between 3 and 4 m. (10 to 13 ft.). Except in the depression areas, ordinary strains of rice adapt themselves best to the conditions prevailing in the Central Plain where the slow-rising flood water up to



After Hammon's New World Atlas 1940

FIG. 8 DENSITY OF POPULATION IN AFE. REGION

DENSITE DE LA POPULATION DANS LA REGION CEAEQ.

a depth of 0.3 to 1.5 m. provides the water required for growth. Although the fluctuations of water level annually do not quite satisfy the water requirements, a good harvest is obtained roughly every two years, while, during the remaining interval a shortage of water rather than flood conditions prevails.

A special variety of deep-water rice, or floating rice as it is generally called, is cultivated in the depressions covering a total area of 1,900 sq. km. which is submerged during floods to a depth of over 4 m. This floating rice can adapt itself to the flood water, its growth keeping pace with the rising flood level provided the latter does not exceed 6 to 10 cm. a day. The stalk can ultimately attain a height of over 4 m. The yield of this type of rice is approximately one and a half to two tons of paddy per hectare.

Not only does the crop adapt itself to the flood, but the people in the area also build their houses on tall piles above flood level or on floating pontoons or bamboo rafts. Floating markets are a common feature along the main waterways.

The above is true also of the lower Mekong plain. Vast areas here from 30,000 to 40,000 sq. km., are inundated annually, in both Cambodia and South Viet-Nam. In Cambodia the flood water rushes through the numerous cuttings of the higher ridge along the banks to the large areas behind, and spreads over the land. Since time immemorial the people of this area have adapted themselves to this natural phenomenon. Agricultural practices in the flooded region have also been adapted to the flood conditions. In areas subject to slight flooding either early strains of rice are planted during March-April and harvested before the high water period or are sown after the drop of high water in November-December and harvested in April of the following year. The depressions behind are used for fish rearing. In South Viet-Nam, floating rice is cultivated near the Cambodia border where the annual flooding from the Mekong attains a depth of from 3 to 4 m. (10 to 13 ft.). On the very flat plain near the coast where the intrusion of salt water might damage the crops during some months of the year before harvesting, a strain of quick growing rice is cultivated. In some parts of the delta where the land dries out three months after receiving some 40 cm. of water from the river flood or rainfall, a special kind of rice "*riz de decrue*" is planted to suit the conditions. The rice is transplanted in 40 cm. of water and grows during the time the water subsides and the land gets dry.

The farming practice adopted in the Province of Kendal in Cambodia is a typical example. Houses are built on the strip of higher land along the river banks, amidst orchards. Further behind on the land side is another strip, one kilometre in width, which, being situated on the slope of the ridge, is not subject to normal flooding and is an area of dry cultivation. Still further back is a considerable area of paddy fields which is cultivated after the floods. And behind

this are the depressions which are used for fish rearing.

The Central Plain of the Chao Phya river and the lower plain of the Mekong river are two of the rice surplus areas of the region, though both produce only one crop of rice a year and the yield per hectare is comparatively low. They may be contrasted with the Pearl River delta of South China which produces two crops a year with a higher unit yield, but the output of which is still insufficient to feed the population. The reason why both the Central Plain of the Chao Phya and the lower plains of the Mekong still have large quantities of surplus rice for export is the lower density of population in these areas, that of the former being 106 per sq. km. and of the latter 100 per sq. km.; while the density of population of the river deltas of North Viet-Nam and China, where dikes have been constructed extensively on the river alluvium, is as high as 500 per sq. km. for the Red River and 1,056 for the Pearl River. Dikes are mostly found in those river deltas where the pressure of population is so great that the inhabitants are compelled to put every inch of arable land under food crops, and to protect it from ravages of floods.

A good example of this is the Pearl River delta where all the arable land is under cultivation. The average amount of land per capita is only 0.095 hectare. Two crops of rice are cultivated annually. The early crop is planted during March-April and harvested in June-July while the second crop is planted in June-July and harvested in October-November. The average yield for the two crops is 3.78 tons of rice per hectare. The available rice supply per capita would thus be $3.78 \times .095 = 0.360$ tons for a normal year, which is sufficient to provide 3,400 calories per head daily. In fact, besides inhabitants of the farms, a vast population outside the delta as well as of the cities such as Canton and even Hong Kong and Macau rely upon food production from the Pearl River Delta. The raising of two crops here would be impossible without protection of the paddy fields by dikes against the annual floods which occur usually between June and October. Paddy is also planted on fresh river deposits not yet reclaimed by the dikes. A fairly satisfactory harvest can be obtained if the flood level is not too high, but the hectare yield is then far less than that of diked farms where perfect control of water for growth of rice is secured.

Comparing the map of population density (Figure 8) with that showing the distribution of dikes in the region (Figure 26) it is interesting to note that the areas with the densest population are those where dikes have been constructed on the river alluvium. The exception is the Ganges Plain whose physiographical features have led to this distinction and will be described later.

Population of river deltas and crop yield

RIVER DELTA	POPULATION DENSITY PER SQ. KM	CULTIVATED LAND HA. PER CAP.	YIELD PER HA. IN TONS				YIELD PER CAP. IN TONS			
			RICE	WHEAT	MILLET	CORN	WHEAT	MILLET	CORN	TOTAL
Chao Phya.....	106	.945	1.00	—			.945			.945
Irrawaddy.....	83	1.200	.99	—			1.19			1.19
Kosi.....	350	.286	.83	—			.24			.24
Mahanadi.....	200	.500	.83	—			.42			.42
Mekong.....	100	1.000	.81	—			.81			.81
Pearl.....	1056	.098	3.78	—			.36			.36
Red.....	500	.200	1.21 ^{a/}	—		.74 ^{a/}	.24		.14	.38
Yangtze.....	550	.182	2.70	1.14			.49	.20		.69
Yellow.....	395	.253	—	.94	1.01		.24	.26		.50

Source : Population figure of river deltas from Bureau of Flood Control, ECAFE : *Replies to Questionnaires on Flood Control* except Burma, from Government of Burma, *Burma Handbook* 1944, p. 10 Yield crops : China : Buck, J. L. *Land Utilization in China*. Others : FAO *Grain Bulletin*, January 1949, *Rice Bulletin*, February 1949.

(a) For the second cropping 50 % of the area under corn at 1.48 ton/ha., and the rest under rice at 0.81 ton/ha.

The above table is a comparison of population density, hectare yield and available food supply per capita of the major river alluvium areas of the region. It is of interest to note that two crops are planted in the most densely populated areas such as the Yellow River, Yangtze River, Pearl River and Red River alluvial plains and deltas where cultivators make the most of the growing season by protection against floods by dikes. In some of these areas growing two crops, not only have the farmers to work twice as hard, but they have to labour practically all through the year on the necessary preparations for cultivation. In the Red River delta in North Viet-Nam, for instance, farmers have to lift water up to a depth of 2 m. into the rice fields during the winter months, by only bamboo baskets or foot paddle pumps ; although the hectare yield is high, the food supply per capita is low because of the extremely dense populations. Here the important role of dikes in assuring the food supply of the people is clearly apparent. On the other hand the great plain of the Mekong and the Central Plain of the Chao Phya river have only one crop a year adapted to the flood conditions with a low hectare yield. But the rice supply per capita is far in excess of the amount required because of the comparatively low population. No protection against flood flow is, therefore, necessary for the present population, and, in fact, the two areas in question are among the principal rice exporting areas of the region.

On the Irrawaddy River of Burma, the gradual development of embankments will be seen to have followed the increase of population. Before 1850 lower Burma, on which paddy is now cultivated, was mainly swampland covered with forests and sparsely popu-

lated. The inhabitants lived in small scattered villages and engaged in fishing, salt extraction and shifting cultivation of paddy on clearings. The total acreage under rice in lower Burma was approximately one-tenth of the area now under cultivation. A rapid increase in cultivation has taken place since then, following the rush of settlers from Upper to Lower Burma. In order to protect fertile areas which were subject to flooding, the construction of embankments or dikes kept pace with the increase of population and the cultivated areas. The following is the order of construction of dikes ⁽¹⁾ — Maubin Island — 1880-1881, Kyangin, Myanaung and Henzada of the Irrawaddy 1881-1882 ; Sagyin-Sugaggi 1887-1888 ; Sittang 1883-1884 ; Thongway 1922-1923 and Tamalakaw 1925-1926. The embankments of the Irrawaddy Delta protect 553,000 ha. (1,310,000 ac.) of paddy fields which is approximately 20 per cent of the total area under paddy 2,650,000 ha. (6,500,000 ac.) in the Delta ⁽²⁾.

PHYSIOGRAPHICAL INFLUENCE ON FLOOD CONTROL MEASURES

The Ganges Plain of India with a very dense population is not much different from the other river alluvium tracts of the region, but has no continuous dike system along the river except for some short lengths in Bihar and in some parts of the Bengal

(1) Government of Burma, *Burma Handbook*, 1944, p. 41, Embankments of the districts Henzada, Maubin, Pegu, Pyapon.
(2) Ibid, p. 23 including Henza, Hanthawaddy, Tharrawaddy, Pegu, Insein, Rangoon, Maubin, Pyapon, Myaungmya and Bassein Districts.

delta. Embankments in the past constituted the sole means of flood control in this region, and were built, as the population increased, to save cultivated lands from inundation. The absence of any continuous dikes along the Ganges, one of the most densely populated regions in the world, however, is explained by the fact that the river's flood conditions are not as serious as those of some other major rivers of the region such as the Yellow, Yangtze, Pearl and Red Rivers. A study of the physiography of the Ganges River basin shows that it lies between high land on either side. To the north is the high Himalayan mountain wall, while to the south is a confused mass of ranges running in a general east to west direction. The latter is connected by the vast Indian plateau of the Deccan to South India. The Ganges plain, or more correctly the Indo-Gangetic plain, since its formation, has been continuously built up by deposits of the mountain ranges on both sides of the river's course. Since this building up process has been caused by deposits washed down from the high mountain ridges on either side of the basin, it has led to the formation of a broad river valley. The general appearance of the cross-section of this river plain is a depressed concave valley with the Ganges flowing along the deepest track. The flow of a river in such a valley is stable. Flood flow simply attains a higher water level and spreads over banks in a belt along the river course.

A contrasting physiography is afforded by the Yellow River. The mountain ridges run more or less parallel to the sea at a distance of from 600 to 800 km. from the coast. The Yellow River emerges from the gorge and debouches into the vast plain which lies between the mountain ridges and the sea and has been built up by the soil of the mountain ridges carried by the river. The vast area of alluvial deposit takes the shape of a cone with its apex at the outlet of the gorge section. The flow of a river on a cone is highly unstable; it can flow through any depression to the sea. The Yellow River has, in fact, changed its course many times within recorded history from Peking in the north to the Yangtze in the south, a distance of over 600 km. A cross section of this vast plain (Figure 25) shows the general shape of this cone, elevated and convex, with the river now flowing on the top of a ridge. Unless the river is confined to a definite course, either by dikes or training works, serious damage follows whenever the river changes its course.

The Kosi River, one of the principal tributaries of the Ganges, also flows on an alluvial cone. The river has its origin in the Himalaya mountains, carries a large amount of silt, and debouches into the Ganges plain almost at right angles to the Ganges River. The Kosi plain thus assumes a conical shape with the apex located at the outlet of the gorge and subject, therefore, to shifting of river course. In 193 years the Kosi has moved 112 km.

DEVELOPMENT OF FLOOD CONTROL METHODS

Embankments, on alluvial plains and river deltas, are the most popular flood control works, not only in the region, but also in the world. Apart from embankments, however, certain measures for storing water in the valleys of the headwaters of rivers can be traced back many centuries in the region. Such measures include the ancient "tanks" of Ceylon. They exist to the present day. A notable example of this is the Minneriya tank, 20 mi. in circumference, which was constructed by King Maha Sena in the Third Century B. C.

In the head water region of the Yellow River the method of retaining the run-off by a system of dikes and intercepting canals was commenced many centuries B. C., and in the head waters of the Yangtze extensive terrace farming, long practised, has admirably conserved soil and water. All these measures, however, appear primarily to have been aimed at retaining the run-off for irrigation and hardly for reducing damage through flooding of areas lying hundreds of kilometres away down-stream.

Dikes were originally constructed by groups of villagers and farmers seeking to defend their small plots against floods. Numerous small dikes exist now in the plains north of the Ganges in Bihar (India) and many can be seen along newly reclaimed lake areas of various countries. Private dikes protected relatively limited areas and were later connected to others nearby. Gradually they came under public or governmental control and were usually strengthened when the area protected grew in economic value. For example, dikes existed in the Yellow River since 603 B. C. They were constructed by the different States or provinces for individual interest. It was only since 69 A. D. during the Han Dynasty that a unified system along the river came into existence.

Dikes on river alluvium and deltas of the region are often of considerable length. The total length of dikes and area protected by dikes are given in app. 1 and shown in Figure 26.

It would appear that dikes were persisted with in many instances, even when they were considered difficult to maintain, uneconomical and positively harmful. For example, around 8 B. C., the dikes along the Yellow River were constructed 25 km. apart. The wide foreshores on the river side were cultivated. In order to protect the reclaimed area from flooding auxiliary dikes were constructed nearer the river and in the course of time these became the main dikes. Villages and towns were built on the wide foreshore. It then became both difficult and expensive to maintain those dikes near the river. Of special interest is the plan of flood control by J. Chia, the highest authority in charge of the Yellow River, prepared in 8 B. C. He recommended that the best solution would be to abandon the considerable foreshore which was

already densely populated, resettle the population, and "return the land to the river", so as to provide ample space for the flood flow. A former Chief Engineer of Bengal, speaking about the Bengal delta, expressed the opinion that confining the flood within the narrow river channel by embankments adversely affected the river regime and that the most effective flood control method was the provision of as wide a waterway as possible, and allowing the flood to spread over as large an area as practicable. Laws were enacted in China before the war prohibiting the further reclamation of land around lakes to preserve their capacity for flood detention. The Pearl River Bureau prohibited further private dike construction on the Pearl River delta. The construction of private dikes, without any consideration of the flood problem of the delta as a whole, has considerably aggravated the gravity of the flood condition.

Besides the defence against floods by dikes, yet another method — river training or regulation — was also developed in some rivers of this region. On the Yellow River, river training work has taken the form mainly of a series of short spur dikes, originally constructed centuries ago. They serve more properly as dike protection than river training. Regulation of the lower Yellow River has long been discussed by officials in charge of the river, and many books written on the subject have been published as far back as 2000 years ago. C. H. Pan (1521-1595) was the keenest and most able of former hydraulic engineers. His plan was to train the river by a system of "louti" (near dikes), thus confining the flow to scour the river bed and by another system of "yaoti" (far dikes) to provide protection from floods. He discussed in detail the effect of diverting the river through many channels and spillways.

On the Pyuntaza plain of the Sittang River in Burma, the method of "River Training Without Embankment" has been successfully developed. The method consists of the use of bamboo stake side fences parallel to the flow of the water with cross fencing whenever required. The object of parallel side fences is to direct the flow of the river along a selected line in the early stage of training, and control overflow or bank spill in the later stage. A vast area of marshland in the Pyuntaza Plain has been converted into intensely cultivated land by this method of training on the small rivers.

Up to the Twentieth Century dikes were the chief means of flood control in the region. With the

introduction of modern engineering methods, the hydraulic structure most commonly employed since 1910 has been the movable sluice built at the junction of a creek and the main stream, and which render unnecessary a long line of dikes along the creek. Since 1920 the planning of flood control by flood detention or storage has been studied for some of the major rivers of China. For instance, the Yungting River flood control scheme of 1925 aims chiefly at reducing the river flood by two detention reservoirs, flood diversion in the lower course and soil erosion check dams in the head waters. Another is the Huai River scheme, which plans to utilize the Hungtze Lake to detain the flood flow. River hydraulic experiment stations have been set up in many countries of the region to study the flood problem and other hydraulic projects.

Since 1940 the idea of multiple purpose unified river basin development has gained ground in many countries of the region due possibly to the success of the Tennessee Valley Authority. Many projects of river basin development have been prepared and some are being carried out, particularly in India, China and Ceylon. They aim at the combined development of water resources for hydro-electric power, irrigation, reclamation and navigation, soil and water conservation and flood control. Of this a good example is the development of the Damodar Valley by an Act passed by the Government of India which created the Damodar Valley Corporation in March 1948 to be responsible for the overall development of the valley. Construction work on the project is now progressing. The Mahanadi Valley Development Project is another important multiple-purpose scheme under construction. Other major projects in India under investigation are: the Kosi project, the Narbada project, the Tapti project and the Rampadasagar project. In China the best known project of this nature is the Yangtze Gorge project, planned and designed during and after the last war. Over 15 million kilowatts of power will be generated from this single project. Though multiple-purpose in nature, the project does not cover development of the whole river basin. The Yellow River basin project, planning of which began in 1946, is another, aiming at combining flood control and other developments. The Kelani project of Ceylon, which is still under investigation, is expected to control floods which cause damage to the capital, Colombo, as well as to provide hydro-electric power.

CHAPTER III

FLOOD DAMAGE AND FLOOD CONTROL ACTIVITIES OF VARIOUS RIVERS OF ASIA AND THE FAR EAST REGION

In describing the flood damage and flood control activities of various rivers of the ECAFE region, the following presentation has been adopted :

- (1) General features of the river basin.
- (2) Floods and flood damage.
- (3) Flood problem and proposed plan of flood control.

(4) Flood control activities.

However, owing to the paucity of data concerning some rivers of the region, a certain amount of flexibility has become unavoidable. The rivers described here are arranged in alphabetical order. The locations of the rivers described are shown on the index map on the front page.

BRAHMAPUTRA RIVER

Summary of basic data

Total drainage area	938,000 sq. km.	361,200 sq. mi.
Length	2,900 km.	1,800 mi.
River slope on delta	1:11,400	
Average rainfall (in valley)	2,160 mm.	85 in.
Average discharge (calculated)	12,100 c.m.s.	428,000 c.f.s.
Minimum discharge (approximate) ..	425 c.m.s.	15,000 c.f.s.
Average annual run-off (calculated) ..	381,000,000,000 cu.m.	308,950,000 ac. ft.
Average annual run-off per unit area	0.019 c.m.s./sq. km.	1.71 c.f.s./sq. mi.

General Features of the River Basin

The Brahmaputra (see figure 9) is one of the longest rivers of India with a total length of 2,900 km. (1,800 mi.) and a drainage area of 938,000 sq. km. (361,200 sq. mi.). Rising in the glaciers of the northernmost chain of the Himalayas in south-west Tibet, under its Tibetan name of Tsang-Po, the Brahmaputra flows for about half its length in a trough, north of the Himalayas, which runs parallel to the main Himalayan range. Then it veers north-east, runs through many gorges in a series of cascades and rapids, makes a hairpin bend and turns south and

south-west. After receiving the waters of its two confluents, the Dihang and the Lohit, the united stream now takes the name Brahmaputra, and from here flows 725 km. (450 mi.) down the Assam valley in a vast sheet of water dotted with numerous islands, the chief of which is 1,260 sq. km. (485 sq. mi.) in area.

The mass of silt brought down from the Himalayas is sufficient to form sandbanks, and even islands in the lower valley, wherever it is blocked by any impediment in the current of the river which thus alters its channel amidst an intricate network of waterways. Broad streams diverge from the main river and rejoin it after a long, separate existence of uncontrollable meandering.

The Brahmaputra with its chief tributaries, the Subansiri, Kameng and Manas on the north bank and the Buri, Dehing, Disang, Dikho, Jhansi and Dhansira on the south, traverses an alluvial plain about 725 km. (450 mi.) in length with an average width of 80 km. (50 mi.). It receives the drainage of the Himalayas in the north and the Assam range in the south, and, continuing its course round the western spurs of the Assam range, the Garo hills, for 280 km. (180 mi.), joins the Ganges at Goalundo from where the river flows under the name of Padma, and reaches the Bay of Bengal by the broad estuary of the Meghna.

Through the greater part of its course in Assam, the Brahmaputra is bounded on either side by stretches of marshy land covered with thick grassy jungle relieved occasionally by patches of cultivated land. Further behind, however, where the elevation is higher, the plain is covered with rice fields and dotted over with clumps of bamboo, palm and fruit trees.

The delta of the combined rivers of Brahmaputra and Ganges comprises an area of 130,000 sq. km. (50,000 sq. mi.) of well-populated and intensely cultivated land. The average slope of the river is 1:11,400, but the actual gradients in different localities vary considerably from the average value. Originating in China and flowing through India and Pakistan, the Brahmaputra has now assumed the character of an international river.

The considerable rainfall in the Brahmaputra is the chief characteristic of the climate of the river basin. The average annual rainfall in the valley is 2,160 mm. (85 in.). The maximum recorded precipitation is at the station Cherra-Punji which has an annual total of 12,100 mm. or 475.61 in. Over 70 % of the annual total falls within the monsoon period from June to October.

No detailed measurements of run-off have, so far, been made for the basin. The run-off as calculated by A. N. Khosla's formula $R = P - XT$ (R = annual run-off from a catchment area in inches, P = annual precipitation on the catchment in inches, T = mean annual temperature of the catchment in degree Fahrenheit, X = a constant which is different for different catchments) comes to 381,000 million cu. m. or 308.95 million ac.ft. The minimum river discharge is roughly 425 c.m.s. or 15,000 c.f.s.

The Himalayan snow begins to melt in March and, with this, the Brahmaputra begins to rise, the floods commencing early in May. By far the heaviest rainfall occurs in the monsoon months. As the main river usually remains in flood throughout these months, some of the tributaries often find their outlets already congested thus aggravating their flood problem. This appears to explain the formation of marshy strips on either side of the Brahmaputra as the surplus water which is unable to discharge fully into the

Brahmaputra forms a back-water on either side of the river and, during usual floods, spreads over the adjacent areas inflicting considerable damage on crops, buildings and property.

The Brahmaputra is a heavy silt-bearing stream, but no observations of silt have been made so far. An intermittent record of observations exists, but the results cannot be taken as conclusive. The experiments carried out at Gauhati in July 1909, show that the proportion of silt by weight is 1 to 976, or 0.102 %.

The tributaries of the Brahmaputra, for most of their lengths, drain the steep slopes of the Himalayas to the south, where rainfall is heavy. Consequently they not only carry heavy run-off, particularly where slopes are denuded of forests, but also a very large volume of detritus — the result of excessive soil erosion. A great amount of this material contributes, without doubt, to raising the land surface in the plains by bank spill, but the major portion of the heavily silt laden floods is carried to the Brahmaputra and not only aggravates its flood congestion, but also adds to the silt charge of the flood. The plain area of the valley has since been built up and is being raised gradually by comparatively coarse material (without much cohesion between the particles) carried down from the hill slopes. The soil is very friable, resulting not only in considerable tortuosity of the streams, but also frequent shiftings of their courses which, in fact, is necessary to a certain extent in the economy of nature, as it is only by such shifting that the alluvial plain can be raised uniformly.

Floods and Flood Damage

A flood of unprecedented magnitude occurred in July 1948. It lasted for a few days and affected Majuli, parts of Kamrup District, Lakhimpur, Sib-sagar, Goalpara, Cachar and Gauhati districts of Assam Province. No details of peak flood, flood volume, flood profile and stage, however, are available. The cause of this flood was continuous rain. The flood situation due to the overflow of river banks and breaches in the embankments assumed alarming proportions and is described as the worst since 1931.

About 80 villages around Gauhati were flooded by the Brahmaputra and its tributaries. In Majuli and Kamrup districts standing paddy and jute crops were completely submerged and destroyed over a wide area. At many places prosperous villages were flooded and inhabitants tried to save as much of their cattle and belongings as they could. Owing to the sudden rise of water, granaries of rice and paddy were destroyed completely at many places. According to a press note the total number of villages affected exceeded 1,000. Five hundred thousand people are reported to have suffered as a result of the flood.

Flood Problem and Proposed Plan of Flood Control.

Along the course of the Brahmaputra and its tributaries a series of marginal embankments has been built. At several places, District Board roads also serve the purpose of the embankments. The results, however, are not considered satisfactory.

In addition to flood control, the other problems of the lower basin are (1) necessity of cheap power

to exploit the mineral resources, (2) extension and improvement of navigation facilities and, (3) in certain areas, extension of irrigation.

As regards improvements of a minor nature such as construction of drainages, local flood protection etc., the Provincial governments are undertaking many schemes every year.

The Central Waterpower, Irrigation and Navigation Commission has proposed a number of multi-purpose schemes for the utilization of water resources of Assam. Eleven dam sites have tentatively been chosen and are listed in the following table :

Proposed projects in Assam of Brahmaputra River

NAME OF TRIBUTARY	LOCATION OF LEFT BANK AT DAM SITE	APPROXI- MATE DRAINAGE AREA IN SQ. MI.	MAXIMUM WATER LEVEL IN FEET	APPROXI- MATE HEIGHT OF MAXIMUM WATER LEVEL ABOVE BED LEVEL OF RIVER IN FEET	APPROXI- LENGTH OF WATER SPREAD AT MAXIMUM WATER LEVEL AT DAM SITE IN FEET	CAPACITY IN MIL- LION ACRE FEET	SUB- MERGED AREA IN ACRES
<i>Someshwari</i>	90° 38' 30" E 25° 13' 30" N	803	400	330	1,980	4.85	35,635
<i>Dihung or Siang</i>	95° 14' 30" E 28° 11' 30" N	100,459	1,000	470	1,900	10.67	64,717
<i>Debang or Sikang</i>	96° 49' E 28° 25' N	4,439	1,750	550	3,300	2.00	6,144
<i>Luhit or Tellu</i>	95° 25' E 28° N	7,926	2,000	350	2,700	1.65	10,240
<i>Noa Dihing</i>	96° 23' E 27° 29' 59" N	74,816	1,700	550	2,000	4.30	11,520
<i>Dikhu or Nunga</i>	94° 47' E 26° 44' 50" N	1,132	1,000	530	2,100	2.75	17,408
<i>Melak (Jhansi)</i>	94° 36' E 26° 43' N	243	1,000	550	2,145	5.55	27,648
<i>Subansiri</i>	94° 14' 45" E 27° 34' N	10,547	1,000	400	1,980	11.35	62,669
<i>Diyung or Dhansiri</i>	94° E 26° 4' 30" E	1,319	900	430	1,815	3.26	20,687
<i>Jai Bharoli or Kameng</i>	92° 50' E 27° 15' 30" N	3,656	1,750	600	3,300	5.35	16,385
<i>Manas</i>	94° 47' 30" N 26° 48' N	11,700	1,000	400	1,900	10.67	64,00

Most of the projects will be designed as multi-purpose projects for power generation, perennial irrigation, extension and improvement of navigation and flood control.

The storage in the proposed reservoirs will ensure a regulated flow of nearly 1,980 c.m.s. (70,000 c.f.s.) in the Brahmaputra, during the dry season. Taken together with the discharge from uncontrolled tributaries and contribution from the perennial flow, it

would be much higher than the lowest discharge in the river during this period. During floods, on the other hand, the discharge will be much less than at present, and, as most of the water from the reservoirs will be free from silt, the regime of the river will improve considerably and navigation throughout the year will be easier than at present. The facility for navigation would be extended further inland along the tributaries and into the reservoirs.

The dams proposed by the Central Waterpower, Irrigation and Navigation Commission are still in an investigation stage and no details have been worked out.

BRANTAS RIVER

General Features of the River Basin

The Brantas (see figure 10) is the second largest river in Java and has its origin in the Ardjuna mountain in the Residency of Malang. It has its estuary in the Straits of Madura, after flowing through the cities of Malang, Blitar, Tulungagung, Kediri, Kertosono and Porong.

The Brantas River has a length of 310 km. (192 mi.) and a drainage area of 9,675 sq. km. (3,730 sq. mi.). A significant feature of the Brantas is that its water contains a large proportion of sand. According to a survey carried out in 1936 the average amount of sand in the water was as much as 1.7 kg. per cu. m. (0.17 % by weight). The sand comes mainly from the river's tributaries running down from the mountains of Kelud and Wilis.

The current of the Brantas does not appear to be able to carry the sand in the water as can be proved by the fact that in the past 10 years the bed of the river in the Kediri region has risen by four cm. annually. As a result, the Brantas overflows its banks during floods and much of the land adjacent to the river is inundated.

Flood Control Activities

Dikes have been constructed along the Brantas as well as its tributaries. Those along the main river begin at the city of Kediri on the right bank and extend to within 7 km. south of Kertosono on the left bank.

The total length of river dikes is 431 km. (268 mi.). They have proved adequate to contain the flood flow, even during the big flood of November 1942 when at the floodgate at Mlirip near Modjokerto a flow of 1,400 c.m.s. (49,500 c.f.s.) was recorded. During floods, however, some areas are still inundated but they are deliberately permitted to be flooded in order to protect the lower regions of the Brantas River.

The Brantas bifurcates at Modjokerto, the two arms being then called the Surabaya River and the Porong River. Through both, the Brantas empties itself into the sea. In the event of an extraordinarily high flood, which cannot be passed by the two arms, serious flooding occurs of most of the Surabaya River basin, including the city of Surabaya, and also of the Porong basin.

In order to protect the lower regions of the Brantas from flood, therefore, some areas upstream are allowed to be flooded for a few days. These areas are :

- (1) Parts around Bening-Gesikan swamp in the vicinity of Toloengagoeng. During the 1942 flood, the greatest recorded so far, as many as 11,000 ha. (27,200 ac.) of rice fields were submerged. Both the swamps act as regulators for the Brantas River. The water of the river's tributaries running down from Wilis Mountain can temporarily be held in the swamps, thus reducing the flood water of the Brantas.
- (2) The portions around Widas River, Kabupaten Ngandjoek with an area of 4,000 ha. (10,000 ac.).
- (3) Rawa Paras with an area of 10,000 ha. (24,700 ac.).
- (4) The part between Mlirip and Marmoyo River.

A close study of the causes of floods indicates that the main factor is the deforestation in the drainage basin of the Brantas River. Rainfall flows freely to the rivers. Heavy downpours erode the soil (sand) which is not protected by vegetative cover and this soil raises the river bed progressively.

According to a report by the Forestry Service, it was revealed that about 14,585 ha. (36,000 ac.) of forest in the river basin between Djengbiru and Pulo-tondo had been devastated by the end of 1947. As a result of the barrenness of the land, formerly covered with thick forest, the discharge of the Brantas River has been greatly reduced in the dry season.

Flood Control Plan

The Irrigation Department has adopted the following programme for the control of floods of the Brantas River :

- (1) Reforestation of the whole drainage area of the river. This is a long-term project.
- (2) Construction of buffer basins. The Bening-Gesikan swamp is a natural detention basin but it is inadequate. It is proposed to construct the Pongadjih storage basin in the upper reaches of the Brantas River. When completed it will furnish hydro-electric power, extend and improve irrigation and navigation and will promote fisheries.
- (3) The building and restoration of dikes. This work is being proceeded with, as circumstances permit, and the dikes may be considered adequate to deal with normal conditions.

CHAO PHYA RIVER

Summary of basic data

Total drainage area	160,080 sq. km.	61,807 sq. mi.
Length of main river (Ping and Chao Phya)	1,000 km.	621 mi.
River slope at Paknampoh	1:7,000	
Ayudhya	1:10,000	
Bangkok	1:25,000	
Average annual precipitation over river basin	1,200 mm.	48 in.
Maximum flood discharge at Wad Thahad (1942)	6,500 c.m.s.	230,000 c.f.s.
Average annual peak discharge at Wad Thahad	3,500 — 4,000 c.m.s.	123,500 — 141,000 c.f.s.
Average discharge at Wad Thahad	960 c.m.s.	33,900 c.f.s.
June-November	1,640 c.m.s.	58,000 c.f.s.
December-May	280 c.m.s.	10,000 c.f.s.
Minimum discharge at Wad Thahad	65 c.m.s.	2,300 c.f.s.
Maximum flood volume at Wad Thahad (1942)	56,737,520,000 cu.m.	45,992,000 ac. ft.
Above base flow 4,200 c.m.s.	22,800,000,000 cu.m.	18,482,000 ac. ft.
Average annual run-off at Wad Thahad	30,200,000,000 cu.m.	24,700,000 ac. ft.
Run-off coefficient at Wad Thahad	25 %	
Maximum silt content at Wat Po Ngam	0.0028 %	
Annual silt run-off at Wat Po Ngam	5,000,000 tons (approximate)	

Total of the lower basin	58,500 sq. km.	22,587 sq. mi.
Uthai, Borapet, Ban-		
Mee	13,116 sq. km.	5,062 sq. mi.
Passak	18,220 sq. km.	7,035 sq. mi.
Main Central Plain		
(Chao Phya and		
Tachin)	27,170 sq. km.	10,490 sq. mi.

General Features of River System

The Chao Phya (see figure 11) is the name given to the lower course of the river flowing through the Central Plain of Thailand which, together with its tributaries from the north, the Ping, Wang, Yom and Nan and the Pasak which joins the main river on the lower course of the Central Plain from the east, forms the whole of the Chao Phya system. The entire river basin of the Chao Phya, together with those of its tributaries, extends from the Gulf of Thailand in the south to the Thai-Burma border in the north.

To the west, the river basin is bounded by the Tennasserim range, which runs in a north-south direction, roughly following the Thai-Burma border, and to the east, it is bounded by the Sraburi group on the boundary of the slightly undulating tableland of the north-east — the Korat plateau — which has a general slope towards the east, with surface run-off discharging into the Mekong.

The total drainage area of the whole river basin is 160,080 sq. km. (61,807 sq. mi.) with subdivision as follows :

Total of the river basin	160,080 sq. km.	61,807 sq. mi.
Total of the upper basin	101,580 sq. km.	39,220 sq. mi.
Ping	38,760 sq. km.	14,965 sq. mi.
Wang	11,970 sq. km.	4,622 sq. mi.
Yom	20,460 sq. km.	7,900 sq. mi.
Nan	30,390 sq. km.	11,733 sq. mi.

The total length of the river, measured from the river source of the main tributary Ping, down along the Chao Phya to the sea is about 1,000 km. (621 mi.) and the length of the river on the plain, from Paknampoh to the sea coast, is 361 km. (224 mi.).

The topography of the river basin can be divided into two distinct parts, with Paknampoh at the confluence of the Ping and Nan as the dividing point. North of Paknampoh is the hilly region, while to the south is the vast alluvial plain. One outstanding feature of the northern part is the general north-south direction of most of the mountain ranges which separate the four main tributaries flowing more or less parallel to each other in the same north-south direction. The general altitude of the mountains varies from 400 to 2,600 m. (1,300 to 8,500 ft.) above mean sea level, culminating in Doi (Mount) Intanon 2,576 m. (8,452 ft.) in the north.

The mountain ranges are well covered with mixed deciduous and evergreen forests. Scattered along the river valley and in the rolling country region are strips or basins of river alluvium, among the most noteworthy being that around Chiangmai, where rice is cultivated. South of Paknampoh and down to the sea, a distance of 361 km. (217 mi.) along the river

is the vast central plain of Thailand, extending between the Korat plateau to the east and the Tennesseerim range to the west to an average width of about 125 km. (75 miles). The total area of the main central plain, including a part of the Meklong River and Bang Pakong River, which is not a tributary of the Chao Phya, is 30,970 sq. km. (11,950 sq. mi.). Characteristic of the topography of the Central Plain are the flatness of the slope and the numerous effluents running parallel and criss-crossing the alluvium. The ground level where the plain commences in the north at Paknampoh, 361 km. (217 mi.) from the sea, is about 23.5 m. (77 ft.). It gradually drops to barely two metres above mean sea level around Bangkok, 30 km. (19 mi.) from the sea. The general slope is 1:7,000 near Paknampoh and gradually flattens to 1:10,000 at Ayudhya some 109 km. (67 mi.) from the sea and then becomes considerably flatter to 1:25,000 near Bangkok.

Flowing down through the Central Plain, the Chao Phya River throws out several effluents. Worthy of mention are the Makham Thao-Thachin, the Noi and the Klong Kradhumprong on the western bank, and the Lopburi on the eastern bank. Except for the Makham Thao-Thachin which runs directly into the sea, all the effluents, after flowing for a certain distance, re-unite with the main river, while numerous klongs (canals) criss-cross the plain. As the whole of the Central Plain has been built up by river deposits during floods which overflow the effluents as well as the main river, the general topography of the plain comprises strips of higher land developed along both sides of the river course, while in between the river and its effluents lie areas of depression. A cross section across two water courses shows the general land surface sloping away from the river with a difference of elevation, from the ridge to the depressions, of approximately three to four metres. This difference of elevation is more pronounced in the upper part of the plain than near the coast.

During the dry season from November to April the low water discharges of the Ping at Chiangmai, the Wang at Lampang, the Yom at Prae and the Nan at Utaradit are 2, 0, 0 and 20 c.m.s. (70, 0, 0 and 700 c.f.s.) respectively. The effluents in the Central Plain, except for Klong Kradhumprong on the west bank and the Lopburi on the east bank, receive no flow from the Chao Phya during the dry season. The vast Central Plain is dried out during this season and the soil is thoroughly hardened with deep cracks developing on the surface.

The South-West Monsoon sets in at the beginning of May and ends in October. It supplies the main precipitation of the year. Floods occur as a result of typhoons crossing the river basin, travelling from east to west, particularly over the upper tributaries. These typhoons originate in the China Sea. Large floods result when cyclonic rains follow each other in quick succession into the basin between August and

September, and hit the watersheds of the Ping and Nan rivers simultaneously.

In general all rivers have their first rise of water level in May or June amounting to about two or three metres above the minimum level, within a period of from one to three weeks. After this there is a fall of from one to two metres during July or thereabout. The second rise of water level follows gradually, reaching a maximum at the end of August or the beginning of September, then gradually subsiding to the normal minimum level in November. As the water level rises, fair quantities of water are drawn into the effluents of the Chao Phya in the Central Plain, those in the north receiving their supplies earlier than those in the south. The drawn in supplies overflow the banks of the effluents and spread out forming large sheets of water in the depression areas between the Chao Phya and the effluents. These sheets of water in the depression areas behind both banks generally flow at a rate of from eight to ten centimetres per second down south. By the time they reach the flat plain of Ayudhya, if the water level of the Chao Phya at Ayudhya reaches a height of from 3.50 m. to 4.20 m. (11.4 to 13.7 ft.) above mean sea level, the main river will overflow its banks. For a long duration of this stage of flow, the main river can head back the water on to the plain and also spread a vast sheet of water over the flat plain below through creeks connecting the main river with its effluents. Figure 11 shows the depth of flooding in the Central Plain, and a comparison of the hydrographs of the Chao Phya River at Paknampoh (Figure 7) at the entrance to the plain and that at Bangkok, shows clearly the storage of flood flow in the plain.

On the vast Central Plain, two million hectares are under paddy. This is the "rice bowl of Thailand" where the greater part of the country's rice, not only for local consumption but also for export, is grown. The export of over one million tons of rice a year is of vital significance to the economy of Thailand.

Floods and Drought

The vast Central Plain is subject to annual flooding. Flood flow spills from the banks of the effluents as well as from the main river and together with the large sheets of water flows slowly across the plain. This is a typical example of the formation of river alluvial plain, where silt in suspension carried by the flood is deposited and gradually raises the ground level. Though flooding occurs annually, not one embankment has so far been constructed as a defence against floods. On the contrary floods prove indispensable to paddy cultivation. The slow rise of the flood level, gradual spreading of the flood waters over the plain and the average depth of flooding of only 0.3 to 1.5 m. (except in the depressions) in normal years, are all particularly conducive to paddy culti-

vation. It is positive, that flood levels which fluctuate annually influence the crops. Too high or too low water levels result in damage to them.

Paddy cultivation in the Central Plain relies on rain water and floods, and follows the topography which may be divided into three distinct categories :

(a) Land on the ridges of the plain. This kind of land comprises roughly 30 per cent of the total area of the Central Plain. It is covered only by the highest floods which give an inundation depth of 0.3 m. Paddy cultivation has to rely mainly on rain water.

(b) The vast area lying between the ridges and the depressions along the upper reaches and the broad, flat sheets of the lower reaches. This is the chief region of garden rice, comprising 30 per cent of the total of the plain. Paddy cultivation here relies on rain water at the beginning of the rainy season right through to August, and hence depends upon the flood water. The depth of inundation of a normal flood is approximately one metre.

(c) Depressions between the river and its branches. The area of depressions is approximately 40 per cent of the total area of the Central Plain. The average depth of inundation during the flood season in the depressions is 3 to 4 m. A special type of rice, floating rice, is cultivated in these areas. Rain water is relied on for ploughing and sowing which have to commence early in the season, in the latter half of April and May, in order that the stalk of the plant can grow tall enough not to be submerged by the rising water level which results from heavy rain, or spill from the river through canals in June. From June onward, as the flood flow spills over the banks and runs into the depressions, the stems of floating rice keep pace in growth with the rise in water level provided that the latter does not exceed 6 to 10 cm. a day. The length of the stem can reach 4 m.

Rice cultivation in the Central Plain shows how the inhabitants of the area have adapted, not only their crops, but also their mode of life to suit the flood conditions. Houses are built on high piles, or on

floating rafts. Floating markets have developed along the waterways. Transportation during the flood season is done entirely by boat.

Normal flooding of the Central Plain is very beneficial to rice cultivation. But the fluctuation of water level of the annual floods, the variation of date and duration of flood occurrence, all of which affect the water requirements, cause damage to the crops. According to the duration curve of water levels at Ayudhya based on the record of the past 117 years, a flood level between 3.5 to 4.0 m. produces a fairly good harvest with less than 10 % of the crop area damaged, which constitute 52 years out of every 117 years or 44.4 per cent. Based on the same data and the data relating to damage and water levels available since 1917, the average annual damage from floods is worked out at 15.3 per cent of the total cultivated area, while that from droughts is worked out at 15.16 per cent of the total. Again, taking the average yield of paddy from 1939 to 1944, in the Central Plain, which amounted to 2,500,000 tons for a total cultivated area of 2,000,000 ha., as a basis for calculation, the average annual loss due to flood is 382,500 tons while that from droughts is 379,000 tons. If the value of paddy is assessed at 740 bahts or 33.6 U.S. dollars a ton (at the average market rate of 22 bahts to 1 U.S. dollar), the average annual flood damage to paddy crops would be U.S. \$ 12,850,000, while that from droughts would be U.S. \$ 12,730,000.

The average annual damage given above is confined to crops only. Data on damage to buildings livestock etc., is available for the extraordinary flood of 1942, which is of the magnitude of a flood occurring probably once in 100 years. The 1942 flood resulted from two successive typhoons which originated in the China Sea and moved across the upper reaches of the Chao Phya River basin with only a very short interval between them. High water prevailed in all the four tributaries as well as in the effluents of the Central Plain. The whole city of Bangkok was flooded for six weeks. The flood damage of different watersheds of the Chao Phya basin is given below :

Flood damage of Chao Phya River in 1942 ⁽¹⁾

	* DAMAGE OF DIFFERENT WATERSHEDS ASSESSED AT 1948 VALUE IN THOUSAND BAHTS							TOTAL SUM	
	CHAO-PHYA	TA-CHIN	PASAK	PING	WANG	YOM	NAN		
1. Standing crops.....	288,609	33,896	4,871	15	4,082	6.2	43,781	378,566	57.6
2. Garden vegetables and fruit trees.....	232,034	7,872	38	5	1,679	777	1,258	243,663	37.2
3. Buildings, furniture & farm implements.....	9,214	2,154	24	—	173	290	109	11,964	1.8
4. Stored grain.....	7,110	2,621	2	—	2,506	30	160	12,429	2.0
5. Work animals.....	4,478	327	41	—	10	6	258	5,120	.7
6. Domestic livestock.....	3,201	925	—	—	19	—	146	4,291	.7
Total	544,646	47,495	4,976	20	8,469	1,715	45,712	653,033	100.
Per cent of total....	83.3	7.3	.8	—	1.3	.3	7.0	100.	

(1) Source : Report of general flood in Thailand in 1942, p. 25, damage given in original table in 1942 value is here converted into 1948 value after being multiplied by 10.

The total damage, assessed at the present market rate of exchange, would be approximately U.S. \$ 30 million. About 4,250,000 inhabitants, including those in the other watersheds of Thailand, were affected by this flood and 5,340 deaths were also reported as a result of it.

Flood Control and Water Resource Development

Since paddy cultivation in the Central Plain relies on flood water, and statistics of damage to crops indicate the equal chances of occurrence of lower water levels which cause droughts, as well as too high water levels which lead to flooding, the development of irrigation is considered very important. The Royal Irrigation Department of Thailand has completed a comprehensive plan for irrigating the Central Plain, in which it is proposed to build a movable diversion dam across the Chao Phya River at Chainat, 95 km. (59 mi.) downstream of Paknampoh. The Chainat dam will head up the water which will flow through the Noi and Supan Rivers as main canals on the western bank, while a new canal will be excavated on the eastern bank. The proposed project will command an area of one million hectares in the plain. The system will supply water which is badly needed during the ploughing and sowing of crops at the beginning of the season, so that the crops can grow to a sufficient height, before the heavy rains of June. In the middle of the annual drought season, the small discharge of the river can be headed up and diverted to supply the crops. Later the spill of the river will still be conducted into the depressions, but will be properly controlled to synchronize with the rise of water level for growth of the plants.

Besides irrigation, minor flood control of floods with ten-year frequency by embankments is included in the scheme. The project will create three waterways for navigation of two-metre draught perennially from Bangkok to Paknampoh. Its other development is 10,000 kilowatts of hydro-electric power for a proposed steel industry 120 km. (74 mi.) from the dam site. The total cost of the project is estimated at 508,600,000 ⁽¹⁾ bahts of which 220,000,000 bahts would be required in foreign currency, which at the official rate of exchange (10 bahts equal 1 U.S. \$) amounts to 22 million U.S. dollars. The total cost calculated at the present rate of exchange is around 36 million U.S. dollars.

Floods larger than those of twenty-five year frequency cannot be controlled by this project. The Royal Irrigation Department has conducted a study of the possible control of the larger floods, such as those of 100-year frequency, by embankments along the river. It was found that the capital investment plus interest and maintenance far exceeded the estimated value of the damage caused by a flood of this frequency. As the larger flood flow results from the simultaneous occurrence of the floods of the main tributaries, particularly those of the Ping and Nan, which have more extensive watersheds, the control of floods could be properly assured by impounding the flood flow in the river valleys of these tributaries, where suitable dam sites are available. This would be a multiple purpose project, which could supply additional flow during the dry season to the proposed Chainat plan, thus providing irrigation for a wider area. Generation of water power is considered very desirable for the development of future industries, since, up till now, no coal has been mined in the country.

(1) M. L. N. Khambu, Report on Irrigation Drainage and Water Communication Project of Chao Phya River Basin, 1949, p. 50.

DAMODAR RIVER

Summary of basic data

Total drainage area	22,000 sq. km.	8,500 sq. mi.
Area of alluvial plain (including the irrigable area outside of the basin)	3,600 sq. km.	1,400 sq. mi.
Length of river	540 km.	336 mi.
River slope		
River source to 240 km. (150 mi.)	1:528	
240 km. to 400 km. (250 mi.)	1:1,760	
400 km. to 540 km. (336 mi. river mouth)	1:5,280	
Average annual precipitation	1,180 mm.	46.5 in.
Maximum annual precipitation	1,630 mm.	64.3 in.
Minimum annual precipitation	780 mm.	30.6 in.
Maximum flood discharge at Rhondia (1935)	12,400 c.m.s.	650,000 c.f.s.
Average annual discharge at Rhondia	315 c.m.s.	11,000 c.f.s.
Minimum discharge at Rhondia	0 c.m.s.	0 c.f.s.
Maximum flood volume	4,600,000,000 cu.m.	3,700,000 ac.ft.
Maximum annual run-off (1946-47)	13,000,000,000 cu.m.	10,600,000 ac.ft.
Average annual run-off	9,954,000,000 cu.m.	8,060,000 ac.ft.
Minimum annual run-off (1934-35)	5,500,000,000 cu.m.	4,460,000 ac.ft.
Average annual silt run-off at Rhondia (1/500 of the monsoonal run-off)	28,350,000 tons.	
Average run-off per unit drainage area above Rhondia (1)	.0158 c.m.s./sq.km	144 c.f.s./sq.mi.

General Features of the River Basin

The Damodar River (see figure 12) rises in the hills of Chota Nagpur, Western Bihar, at an elevation of 600 m. (2,000 ft.). It flows generally in a southeasterly direction for about 290 km., (180 mi.) through the province of Bihar and enters the deltaic plains below Raniganj. Some distance below this point, the Damodar, in the vicinity of Burdwan, abruptly changes its course to a southerly direction, and flows into the Hooghly River about 48 km., (30 mi) below Calcutta. The total length of the river is 540 km. (336 mi.). The principal tributary is the Barakar River, which joins the Damodar from the north as it emerges from the hills.

The topography of the valley varies from the rough hilly section in the upper portion of the drainage area to the flat deltaic plain of the lower region. The total drainage area of the river is about 22,000 sq. km. (8,500 sq. mi.), of which 18,000 sq. km. (6,960 sq. mi) is the drainage area of the upper Damodar River, just at its confluence with the Barakar River.

The catchment basins of the upper Damodar and Barakar rivers, which comprise the upper portion of the drainage area, are generally denuded of forests

or vegetation cover. The heavy downpours of the monsoon season badly erode the land and cut deep gullies. Some parts of the land located generally near the mouths of the various tributaries have been terraced for agriculture, mainly for the cultivation of paddy. The raising of crops is possible only during the monsoon months, as irrigation has not been developed in the upper valley. Failure of the monsoon, or scarcity of rainfall at the proper time, causes frequent damage to crops.

Frequent overflows during flood period have led to a heavy deposit of alluvial soil in the lower portion of the valley, below the confluence of the Barakar and upper Damodar rivers. About 93 km. (58 mi.) below the junction of the Damodar and Barakar River over a length of 120 km. (75 mi.). This embankment during floods by an embankment which stretches from this point to the mouth of the Damodar River over a length of 120 km., (75 mi.). This embankment has been frequently breached by floods. The right bank, which was once also protected by a dike and abandoned later, is at a generally higher elevation than the left bank.

The rainfall in the Damodar valley averages about 1,180 mm. (46.5 in.) per annum, varying from a maximum of 1,630 mm. (64.3 in.), to a minimum of 780 mm. (30.6 in.) per year over a 33-year period. Eighty to ninety-five per cent of the average annual rainfall occurs during the monsoon months from June to October.

(1) Drainage area above Rhondia 19,900 sq. km. or 7,690 sq. mi.

Monsoon storms, originating in the Bay of Bengal, generally travel in a north-westerly direction towards the Damodar Valley. Storms are more frequent and of greater intensity during the first half of the monsoon season.

Average storm rainfall, occurring during the monsoon months from 1930-1942 in the catchment area of the Damodar and Barakar rivers above their junction, which exceeds an intensity of 13 mm. (0.5 in.) per 24 hours, varies from 47 mm. (1.84 in.) to a maximum of 262 mm. (10.37 in.).

Stream flow records at the Anderson Weir at Rhondia are available intermittently from July 1932 to July 1933, and more continuously from July 1933 till now. In addition, gauge height records taken at Jujuty are available from July 1901 to October 1937. The average annual stream flow at Rhondia for the period of record amounts to about 315 c.m.s. (11,100 c.f.s.), with a maximum annual mean of 415 c.m.s. (14,600 c.f.s.), and a minimum annual mean of 174 c.m.s. (6,170 c.f.s.).

The mean of weekly flow varies from a maximum of 3,610 c.m.s. (128,300 c.f.s.) to a minimum of nil.

Floods and Flood Damage

Floods occur during the monsoon season from the latter part of June to the middle of October. Peak flows exceeding 17,000 c.m.s. (600,000 c.f.s.) were recorded in the years 1823, 1840, 1913, 1935, and 1941, and a peak flow of 18,400 c.m.s. (650,000 c.f.s.) has been recorded twice during recent times, in August 1913 and August 1935, with a flood volume of 4,600 million cu. m. (3.7 million ac. ft.) and 1,820 million cu. m. (1.47 million ac. ft.) respectively. It is also reported that the flood of late July 1840 was similar in size to that of 1913, and that the flood of August 1823 considerably larger. The peak flow for August 1913, and August 1935 floods was almost equal to that for the October 1941 flood, but the volume of flood flow in excess of 2,800 c.m.s. (100,000 c.f.s.) for the last named flood was considerably less than the corresponding volume of the August 1935 flood.

In the design of flood control, a peak flow of 28,300 c.m.s. (1,000,000 c.f.s.) for early monsoon and 21,100 c.m.s. (750,000 c.f.s.) for the latter half of monsoon has been adopted, with a corresponding flood volume of 9,000 million cu. m. (7.27 million ac. ft.) and 6,720 million cu. m. (5.43 million ac. ft.) respectively.

Though comparatively small in size, the Damodar ranks high among India's rivers in its destructive capacity. Embankments on the left bank of the lower Damodar have been frequently breached by floods. The damage can be particularly heavy, because the river cuts across the main arteries of road and rail communications between Calcutta and North India, and lies close to the city of Calcutta, while the thickly populated valley through which it flows contains large

areas of fertile agricultural land, especially in its lower reaches.

The moderate flood of 1943, due to a breach of the left embankment, inundated vast areas west of Calcutta. The loss of crops, cattle and property tallied over Rs. 10,000,000, excluding damage to agricultural land and indirect losses resulting from dislocation of communications and interference with business activities. The cost of traffic diversion along the East India Railway amounted to more than Rs. 5,300,000. Costs of repairs to roads and railways, including the construction of new waterways, culverts and bridges, doubtless exceeded by many times the cost of traffic diversion alone.

In the absence of adequate statistical information, it is not possible to evaluate exact figures of average annual direct and indirect damage. However, damage by minor floods to the paddy crop can, on an average, be estimated at Rs. 2,550,000 annually. If another Rs. 500,000 is added to cover damage to communications, buildings etc., the average annual flood damage may be assessed at approximately Rs. 3,050,000.

Flood Problem and Proposed Plan of Flood Control

Floods result from the intense rainfall and consequent swelling of the river. The lower channel, with the left embankment, is inadequate to discharge the large floods which frequently breach dikes and submerge the lowland. The present channel below Jamalpore is not considered safe with a flood of the magnitude of 5,700 c.m.s. (200,000 c.f.s.). The frequency of floods from 5,700 c.m.s. (200,000 c.f.s.) to 8,500 c.m.s. (300,000 c.f.s.) is 55 per cent, or occurs roughly once in every two years. It has, therefore, after careful and detailed study over many years, been decided to store and detain the flood in the upper valley and concurrently develop water power and irrigation thus making flood control a part of the multiple-purpose scheme.

The flood control plan provides for cutting down the peak of the design flood from 28,000 c.m.s. (1,000,000 c.f.s.) to 7,100 c.m.s. (250,000 c.f.s.) which the lower river channel can safely pass with embankments of limited height.

An autonomous organization, the Damodar Valley Corporation (D.V.C.), was established in March 1948 by the Government of India. The D.V.C. came into existence on 7 July 1948 and has been authorized to handle the unified development of the whole Damodar River basin.

The scheme adopted by the D.V.C. includes the following :

- (1) Eight multiple-purpose storage reservoirs, two additional diversion structures for hydro-electric power and one steam-plant.

Main feature of the 8 dams in the Damodar River Basin

PROJECT	STRUCTURE	DRAINAGE AREA	LENGTH	HEIGHT	STORAGE CAPACITY										AREA submerged	INSTALLED CAPACITY		
					Total to top of gate				Dead storage Available for Flood Control									
		SQ. KM.	SQ. MI.	M.	FT.	M.	FT.	MIL- LION CU. M.	THOU- SAND AC. FT.	MIL- LION CU. M.	THOU- SAND AC. FT.	AUGUST MIL- LION CU. M.	OCTOBER MIL- LION CU. M.	SQ. KM.	KW.			
Aiyar	Rockfill dam with rolled earthfill core	4,240	1,640	6,435	21,120	76	250	1,635	1,330	209	170	988	804	527	429	81	31	45,000
Komar — 1	Rockfill dam with rolled earthfill core	960	370	2,440	8,000	38	125	344	280	61	50	209	170	116	95	26	10	10,000
— 2	Concrete diver- sion weir with flash board					7	23											6,750
— 3	Concrete dam and spillway	1,140	440	628	2,060	45	150	68	56	49	40					6	2.3	10,000
Bokaro	Rockfill dam with rolled earthfill core	520	200	975	3,200	48	160	196	160	36	30	116	95	61	50	14	5.6	3,200
Bermo	Concrete diver- sion weir	6,800	2,630	609	2,000	11	37											18,000
Panchet hill	Sand and gravel fill dam with con- crete wall	0,960	4,234	2,710	8,900	39	130	1,198	970	182	148	904	735	439	357	130	50	40,000
Tilaiya	Stone masonry	980	380	305	1,000	30	100	362	295	74	60	215	175	116	95	55	21	6,000
Balparhari..	Rockfill dam with rolled earthfill core	5,400	2,086	2,986	9,800	35	115	500	407	137	112	223	182	102	83	55	21	20,000
Matihon ...	Sand and gravel- fill dam with con- crete core wall	6,290	2,430	975	3,200	48	160	1,140	930	209	170	735	595	332	270	94	36	40,000
Total		37,290	14,410					5,435	4,428	957	780	3,386	2,756	1,693	1,379	461	176.9	198,950

- (2) A barrage with a network of canals and distributaries to irrigate 392,000 ha. (967,117 ac.) of land, including 73,000 ha. (180,000 ac.) already under irrigation.
- (3) A 146-kilometre (90 mi.) long navigation canal connecting the Damodar with the Hooghly River about 48 km. (30 mi.) above Calcutta.
- (4) Power transmission grids which include initially 320 km. (200 mi.) of 132 kv.; 48 km. (30 mi.) of 66 kv. and 146 km. (90 mi.) of 33 kv. power lines.

The main features of the eight dams are given in the accompanying table.

Regarding flood control, the reduced peak flood on the lower reach is limited to 7,100 c.m.s. (250,000 c.f.s.) from the design peak flow of 28,000 c.m.s. (1,000,000 c.f.s.) which is approximately 50 per cent greater than the peak flow which occurred during the record period over the past 20 years. The maximum controlled peak of 7,100 c.m.s. (250,000 c.f.s.) is governed by the maximum run-off from the uncontrolled drainage area below the reservoir system, including some discharge through the sluice gates of the upstream dams. The work required on the lower river to protect the land against the overflow from a discharge of this magnitude includes the strengthening and continued maintenance of the present embankment on the left bank of the lower river, as the present safe channel capacity is only 5,700 c.m.s. (200,000 c.f.s.). It is calculated that the right bank will be flooded when the flow reaches about 5,000 c.m.s. (200,000 c.f.s.). Detailed studies are required to determine the effectiveness of a low embankment on the right bank.

The total capacity of the reservoirs is 5,450 million cu. m. (4.4 million ac. ft.), of which 959 million cu. m. (780,000 ac. ft.) would be dead storage. As the silt run-off of the river may be assumed to be 1/500th of the volume of the monsoon, it would take approximately 80 years to fill up the dead storage. However, control of erosion in the upper basin is to be initiated to prolong the life of the reservoirs.

The total capital cost of the scheme, not including navigation is estimated (1945-1946) as follows :

Dams and reservoirs ..	Rs. 282 million
Irrigation	Rs. 50 million
Power installations	Rs. 147 million
Miscellaneous	Rs. 71 million
Total .	Rs. 550 million

The allocations for various phases of development are as follows :

Flood control	Rs. 140 million or 25.5 %
Irrigation ...	Rs. 130 million or 23.6 %
Power	Rs. 280 million or 50.9 %
Total	Rs. 550 million or 100.0 %

The annual costs (including interest, depreciation, maintenance, administration) for the different engineering undertakings are :

Flood Control	Rs. 5.40 million
Irrigation	Rs. 5.25 million
Power	Rs. 21.04 million
Total	Rs. 31.69 million

The annual benefit to be derived from the development scheme is estimated as follows :

Flood Control (prevention of flood damage for minor floods only).	Rs. 2.55 million
Power (Rs. 0.0044/kwh.)	Rs. 36.00 million
Irrigation (Value of increased production of crops from irrigation. Additional capital required to produce the increased crops has not been deducted from this amount to assess the net benefit)	Rs. 187.50 million

Flood Control Activities

Since the establishment of the Damodar Valley Corporation, intensive work has been carried out on preliminary studies of the scheme. Engineering features of the eight proposed dams have been thoroughly studied. Complete drawings of the Tilaiya Dam have been prepared. Tenders have been invited and orders placed for electrical equipment. Construction camps, provided with all essential services, are being set up at several dam sites.

The main object of the D.V.C. is to execute the whole programme within the shortest possible time, so as to reduce expenditure in the shape of interest on capital and to increase agricultural and industrial production of the Damodar Valley. The D.V.C. intends to complete the entire scheme within a period of five years. To achieve this, the D.V.C. considers financial assistance from foreign countries necessary.

GANGES RIVER

Summary of basic data

Total catchment area	905,000 sq. km.	350,000 sq. mi.
Jumna	72,000 sq. km.	27,752 sq. mi.
Son	67,000 km.	26,000 sq. mi.
Ram Ganga	82,800 sq. km.	32,000 sq. mi.
Gogra	128,000 sq. km.	49,410 sq. mi.
Gandak	44,400 sq. km.	17,130 sq. mi.
Kosi	61,600 sq. km.	23,808 sq. mi.
Length of main river	2,580 km.	1,600 mi.

Annual precipitation of river basin

Upper part	750 mm.	30 in.
Middle part	1,000 mm.	40 in.
Delta	1,900 to 2,500 mm.	75 to 100 in.
Maximum flood discharge at Faracca	60,200 c.m.s.	2,125,000 c.f.s.
Mean annual discharge	14,100 c.m.s.	498,000 c.f.s.
Minimum discharge	1,740 c.m.s.	61,500 c.f.s.
Maximum silt content (Oct. 1948 -- May 1949) at Faracca		0.1 %
Minimum silt content		0.005 %

General Features of the River Basin

The Ganges River (see figure 9), flowing mainly on the Hindustan Plain, is bounded by the great Himalaya ranges in the north and the Indian plateau in the south. The Hindustan Plain is a major part of the great Indo-Gangetic Plain, which extends from the Bay of Bengal in the east to the Afghan frontier in the west, for a distance of more than 3,200 km., (2,000 mi.), with New Delhi standing on the watershed, west of which the Indus river flows to the Arabian Sea. The width of this Hindustan or Ganges plain is from 240 to 320 km. (150 to 200 mi.). The alluvium slopes gently to the Bay of Bengal with an average gradient of approximately 1:6,000. Rivers originating from the mountain slopes of the Himalayas on the north and those with their sources at the Deccan plateau on the south, flow down from both sides to the plain forming a fishbone shaped drainage area.

The Ganges basin including its tributaries extends from latitude 22°26' N to 31°26' N and from longitude 73°35' E to 90° E, having a total drainage area of 905,000 sq. km. (350,000 sq. mi.). The total length of the Ganges proper is approximately 2,580 km., (1,600 mi.).

The source of the Ganges is near the Gangotri Glacier of the Himalayas with an elevation of over 7,000 m. (23,000 ft.). Flowing only for a short distance of approximately 160 km., (100 mi.) on the steep slopes of the mountain ranges, the river takes its course on the alluvium and in a south-eastward direction for a distance of 640 km. (400 mi.), till it reaches Allahabad, where it is joined by the Jumna. The river then flows generally in a eastward direction till it is joined by the Ghugri and turns south-eastward. On this stretch the Ganges receives the flow of many tributaries, the Ram Ganga, Gogra, Gandak, Kosi, Mahananda, from the north and the Son from the south.

Flowing on the upper portion of the alluvial plain till the junction with the Gogra in the United Provinces, the main river is rather stable. No embankments have been constructed along the Ganges above the Gogra. The river overflows its banks in certain reaches during flood seasons. Around Cawnpore (190 km., above Allahabad, the junction of Jumna),

the left bank is flooded to a width of 8 km. (5 mi.). Along the river for a distance of 130 km. (80 mi.), both banks are flooded extensively attaining the maximum width of about 25 km. (16 mi.) above Chapra. The last is the worst affected area due to the overflow from the Gogra. However the flood lasts only for a few days.

From the junction of Gandak at Bankipore near Patna to the junction of Ghugri, the Ganges flows in the Province of Bihar. The river is both wide and deep at all times of the year. Along both banks of the Ganges in this stretch, for a distance of approximately 260 km. (160 mi.), embankments have been constructed in short lengths. The total length of the embankments on both sides amounts to approximately 420 km. (260 mi.).

The Ganges then flows further southward and enters the delta in Bengal. Here the river throws off a number of spill channels. Taking the Padma as the main channel to the sea, the mighty Brahmaputra joins the Ganges near Goalundo. The important spill channels to the south are the Bhagirathi-Hooghly, the Jalangi, the Bhairab, Mathabhangra and the Gorai, which split into numerous creeks when approaching the sea. Till about the end of the fifteenth century, the main course of the Ganges was through the Bhagirathi-Hooghly. Then gradually it diverted through the Padma, leaving the Bhagirathi-Hooghly as a spill channel, which is being fed only during high water season by the Ganges and supplemented by the Mor, the Ajay and the Damodar.

On the Ganges delta, or more properly the Ganges-Brahmaputra delta, lands criss-crossed by numerous creeks and distributaries are encircled by embankments, mainly constructed by local inhabitants. The triangular deltaic area bounded by the river Padma on the left and the Bhagirathi-Hooghly on the right amounts to about 60,000 sq. km. (23,000 sq. mi.), which is the most fertile area of the basin.

The normal rainfall of the river basin varies from about 750 mm. (30 in.) on the western part to 1,000 mm. (40 in.) along the middle course and to 1,900 to 2,500 mm. (75 to 100 in.) near the delta. Precipitation occurs mainly during the South-West Monsoon period from June to October. Cyclones originating from the Bay of Bengal or China Sea during the monsoon season travel along the basin from east to west.

The maximum recorded peak discharge of the Ganges at Faracca above the junction of Brahmaputra, is 60,200 c.m.s. (2,125,000 c.f.s.). The probable one hundred years' flood is worked out as 74,000 c.m.s. (2,610,000 c.f.s.). The mean annual discharge from 1945 to 1949 was 14,100 c.m.s. (498,400 c.f.s.) while the minimum discharge was 1,740 c.m.s. (61,500 c.f.s.). The total flood volume above a base flow of 11,300 c.m.s. (400,000 c.f.s.) of the 1945 flood having a peak discharge of 54,000 c.m.s. (1,900,000 c.f.s.) over a duration of 129 days was 388,000 million cu. m. (314 million ac. ft.).

The most important tributaries of the Ganges are briefly described below :

Jumna. The Jumna rises in the Himalayas and enters the plains near Dehra Dun. It flows almost parallel to the course of the Ganges on the west and joins the main river at Allahabad. The drainage area is 72,000 sq. km. (27,752 sq. mi.). The river runs mainly in a deep narrow course overflowing its banks in a limited width of approximately 1 to 2 km (.6 to 1.2 mi.) during floods.

Son. The second important tributary on the right bank is the Son which rises in the hills of Chota Nagpur in Rewa (Maikala range) and falls into the Ganges above Patna. It drains an area of 67,000 sq. km. (26,000 sq. mi.) and has a length of 781 km. (487 mi.). The maximum recorded discharge is 34,500 c.m.s. (1,214,000 c.f.s.), the mean discharge 1,110 c.m.s. (39,378 c.f.s.) and the minimum discharge 17 c.m.s. (614 c.f.s.).

Ram Ganga. The first main tributary on the left is the Ram Ganga which rises in the lower Himalayas near the hill station of Naini Tal, where a number of small tributaries join it. The total catchment area is 82,800 sq. km. (32,000 sq. mi.). It overflows the banks during floods from the confluence with the Ganges upward to a distance of approximately 160 km. (100 mi.).

Gogra. The Gogra is a snow-fed river having its source in the foothills of the Himalayas and runs southeasterly into the Ganges near the town of Chapra. In 1779 the Gogra used to join the Ganges west of Chapra, but gradually the confluence has shifted 27 km. (18 mi.) toward the east over a period of 170 years.

The catchment area of the Gogra is 128,000 sq. km. (49,410 sq. mi.) lying partly in the Nepal Hills and partly in the plains of the United Provinces and Bihar. The slope near the hills is fairly steep and gradually flattens out as it approaches the plain where the slope of the country is only 1:9,700.

There is a network of minor streams which flow into the Gogra. Fed by the overflow of the Gandak during the rains, they become practically dry in the hot weather. Each of these streams has numerous small tributaries which, as a rule, take their rise in large swamps. For the most part, they are mere

overflow channels which relieve the low lands of surplus water during the rains, and at other seasons of the year dry up, leaving stagnant pools or marshes in the deeper portions of their beds.

Erosion and deposition are constantly taking place along the banks of the river. The Gogra is proverbial for the number and variety of its changes.

There were several private embankments along the left bank of the Gogra to check the floods. They were not well maintained and eventually were either breached or overtopped. Some of these have been repaired by the Government in 1939.

The Gogra has two important tributaries in the United Provinces, the Sarda on the right and Rapti on the left, both of which overflow their banks during the flood season, inundating large areas on both sides of their course.

Gandak. The headwaters of Gandak, the Kali Gandak and the Buri Gandak rise in the central mountain basin of Nepal. The united stream, after passing through the Deoghat hills, 30 m. north of the Indian territory, flows southwards in a succession of rapids and pools until it reaches the Someshwer range near the Indian border. Here the descent is very rapid and its course lies through a narrow gorge between high cliffs. The Gandak finally leaves the hills through a pass in the sandstone ranges to the west of Someshwer hills. It flows then in a southeasterly direction on the plain and falls into the Ganges opposite Patna. The total catchment area is 44,400 sq. km. (17,130 sq. mi.).

The Gandak is unique among Bihar rivers, as it has been provided with marginal embankments on both banks for a distance of 160 km. (100 mi.) from its outfall. These are now maintained by the Government.

The highest flood recorded near the outfall to the Ganges was in 1941 with a discharge of 4,000 c.m.s. (142,000 c.f.s.) and the mean annual flow is 910 c.m.s. (32,170 c.f.s.).

The embankments on both banks prevent spilling, and the marginal lands between the two embankments are inundated occasionally.

Buhri Gandak. The Buhri Gandak, known as little Gandak or Sikrana, rises in the western extremity of the Someshwer hills and flows from the northwest to southeast till it joins the Ganges below Monghyr. It rises with great rapidity during the rains and abandoned channels which were considerably affected by the earthquake of 1939. They now function the Nepal foothills, there is a continuous chain of old and abandoned channels which were considerably affected by the earthquake of 1939. They now function neither as spill channels nor as drainage channels. As a result large areas remain submerged during the rains to a depth of 1.2 to 1.5 m. (4 to 5 ft.).

The highest flood recorded in 1936 gave a channel discharge of 940 c.m.s. (33,000 c.f.s.) and a spill discharge of 1,870 c.m.s. (66,000 c.f.s.).

The Buhri Gandak is very liable to change its course and old beds, which the stream has now deserted, are extremely common.

Originally the river, near its outfall into the Ganges, was known as Baghmatti, but subsequently when the Baghmatti diverted into Kreh, it became known as Buhri Gandak.

Kosi. The details of the Kosi river are given in a separate chapter.

Flood damage and flood control activities

In the upper portion of the Ganges river up to the confluence of Gogra, or within the United Provinces, inundation due to normal floods is limited only to the strip of land along both banks of the Ganges.

Ordinary floods last only for a few days and the inundations are not considered very serious except in the triangular area bounded by the Ganges and the Gogra at the confluence.

Lower down in Bihar, on account of the numerous streams running from the Himalayas into the Ganges where rainfall is heavy, the country is subject to possibly serious flooding during the monsoon.

In the river deltaic area of Bengal, the problem of flooding by rivers is less serious than that caused by the local heavy precipitation on the low lying lands. Silting of the effluents, after the Ganges diverted its flow from the Bhaghirathi to Padma, has aggravated the drainage problem.

Following heavy rainfall early in August 1938, large tracts in the eastern districts of the United Provinces and parts of Bihar and Bengal were inundated by very heavy floods which had caused widespread damage and distress. An executive engineer was deputed by the United Provinces Government to investigate the causes of these floods, and to suggest suitable remedial measures. He submitted his report at the end of 1938. This report was considered by an Inter-Provincial Flood Conference in January 1939, convened to study the flood problem generally as it affected the three provinces of United Provinces, Bihar and Bengal. A technical committee of the Inter-Provincial Flood Conference recommended, inter alia, the constitution of a Ganges River Commission, whose duties would be to deal with all questions covering the conservancy of the Ganges River Basin, but this recommendation was not implemented, and no further action appears to have been taken till recently.

Since the flood problem of the Ganges basin is being dealt with separately by the different provinces concerned, the flood control activities of each province concerned are briefly described below :

United Provinces.

The big flood of 1948 caused enormous damage in the United Provinces. The flood affected 1,410,000 ha. (3,479,000 ac.) of farmland, 4,000 villages and 4,092,000 persons. A sum of Rupees 486,882 was spent in relief

in 1948-49 and Rupees 205,793 in 1947-48. In addition, the following remissions had to be given on account of damage to crops.

	Remission in Rupees		Suspension in Rupees		Total Ru.
	Rent	Revenue	Rent	Revenue	
1947-48	1,800,000	700,000	227,000	79,000	2,806,000
1948-49	2,300,000	300,000	2,300,000	700,000	6,100,000

This does not include the huge loss from the damaged crops.

After the big floods of 1948, the United Provinces Government appointed " the United Provinces Flood Relief Committee " which met on 27 November 1948. The terms of reference of this committee are as follows :

- (1) To make a close survey of the areas which were flooded during the rainy season of 1948 ;
- (2) To make a study of the past history of floods in the province, to find out tracts which are subject to floods every year or periodically, and to discover whether there is any regular cycle ;
- (3) To examine the causes of the floods and their incidence in various parts of the province ;
- (4) To suggest measures to prevent floods or minimize their adverse effects with due regard to the needs of the province and financial and other limitations ;
- (5) To consider what relief operations should be undertaken so as to afford, with the greatest possible promptitude, adequate relief in areas visited by floods ; and
- (6) To examine the rules for the grant of relief in rent and revenue on account of damage caused by floods, and to suggest changes therein, if necessary.

The present policy of the United Provinces Government appears to be to evacuate the population of flood-affected areas to places of safety till some other measures can be taken. The opinion of the engineers in the United Provinces is not in favour of embankments along the river, except those around, the villages which were, in the past, constructed by the villagers themselves, but are now being repaired and maintained by the government.

Briefly, the problem of combatting the devastation caused by extraordinary floods is proposed to be tackled in three different stages, viz., before, during and after floods, and the following action has been recommended :

- (1) To have a complete survey of the human and material resources available so that local authorities may not have to chase around in search of necessary articles when the flood actually arrives ;
- (2) To take steps to ensure that the requisite number of boats are readily available in times of emergency ;

- (3) District officers should have timely information of floods and make proper arrangements for communicating flood warnings well ahead to those persons who are likely to be affected by the quickest possible means ;
- (4) To plan the evacuation of persons from affected areas in case of danger, and to allot places of safety (flood posts) situated on high land to every 5 or 10 villages, where persons from these villages can be transferred ;
- (5) To clearly mark flood posts and make them thoroughly known well in advance, and to equip them with all the necessities of life, and
- (6) To persuade villagers of areas liable to severe flood to remove a part, or whole, of their grain stock to places of safety.

Bihar.

The position in Bihar is, however, different.

On the Ganges, embankments have been constructed in short lengths to protect some of the towns and important villages. Embankments also exist in some parts of the tributaries such as the Gogra, Gandak, and Sikrana. Besides those along the tributaries, numerous scattered embankments were constructed on the vast plain north of the Ganges to protect the villages and farms.

The question of floods and bunds on the Ganges and its tributaries in Bihar has been a matter of concern to the provincial government for a considerable time, but so far as is known every problem has been tackled as an individual case of purely local interest. Since the earthquake of 1934, however, the problem has been handled more systematically.

In North Bihar practically the whole area is subject to devastating floods. The whole of North Bihar may be considered as a huge inland delta, as all the principal rivers emerging from the mountainous regions debouch in the plain and eventually flow into the Ganges. The only substantial proposal under consideration for flood control now is the Kosi Dam which is expected to solve the problem of this river as well as of its various tributaries and effluents.

Bengal.

The policy in Bengal is against embankments. It is considered that in deltaic Bengal, flushing of land during floods is not only necessary to raise and fertilize the land, but that this process is essential for the conservancy of river itself.

Lower down the Bengal Delta, the problem is somewhat different. Large areas have been reclaimed which are below the high tide level and were, in the past, drained efficiently through the effluents of the Ganges. Since the diversion of the Ganges into the Padma, the rivers of the Bengal delta such as the Bhagirathi, Jalangi, Bhairab and Mathabhanga are dead, or are gradually dying, and their beds, which were very deep, are now much above the low tide level. The dying process is considerably hastened near the sea, due to the tides bringing in large quantities of silt from the sea and depositing it in the beds of these rivers.

The construction of the Ganges Barrage at Farracca is proposed to revive the Bhagirathi and other effluents lower down.

HAI RIVER

Summary of basic data

Total drainage area of Hai River system	210,120 sq. km.	81,100 sq. mi.
Peiyun River	10,000 sq. km.	3,860 sq. mi.
Yungting River	54,040 sq. km.	21,000 sq. mi.
Taching River	34,640 sq. km.	13,400 sq. mi.
Tze-ya River	50,600 sq. km.	19,600 sq. mi.
Nanyun River	60,840 sq. km.	23,500 sq. mi.
Length of rivers		
Peiyun River	200 km.	124 mi.
Yungting River	500 km.	310 mi.
Taching River	300 km.	190 mi.
Tze-ya River	440 km.	270 mi.
Nanyun River	380 km.	236 mi.
Total length of dikes	2,607 km.	1,620 mi.
Average annual precipitation	473 mm.	19.4 in.
Maximum discharge of Yungting River at San Cha Tien (1924)	5,000 c.m.s.	177,000 c.f.s.
Minimum discharge of Yungting River at San Cha Tien (1931)	0.8 c.m.s.	28 c.f.s.
Maximum silt content of Yungting River at San Cha Tien.	55.73 % (by weight)	
Annual silt run-off of Yungting River	42,000,000 tons	

General Features of the River Basin

The Hai River system (see figure 13) comprises the Peiyun River (North Grand Canal), the Yungting River, the Taching River, the Tze-ya River and the Nanyun River (South Grand Canal) and is the most important river system of North China. With the exception of the Peiyun and Nanyun which, more correctly are artificial waterways crossing the great alluvial plain from the south and north, the other rivers of this system combine to form a single water course, the Hai Ho, which carries the flood flow to the Gulf of Pohai.

A characteristic feature of the general topography of the river basin is the vast alluvial plain between the sea coast on the east, and the mountain ridge running in an arc roughly parallel to the shore line on the west and north-west, which rises abruptly from the plain, approximately 300 km. (190 mi.) away from the sea. The hilly region is well covered with wind-blown "loess" from which the great alluvium derives. The total drainage area of the Hai system is 210,120 sq. km. (81,100 sq. mi.). The lengths of the three most important tributaries, the Yungting, Tatsing and Tze-ya are 500, 300 and 440 km. (310, 190 and 270 mi.) respectively.

The flood flow of the Peiyun and Nanyun, which are artificial canals following existing waterways on the alluvial plain, is not considered serious, while that of the other tributaries like the Yungting, Tatsing and Tze-ya, all of which have their sources in the mountain ranges and have large drainage basins, is mainly responsible for the flood problem.

Dikes were constructed exclusively along both sides of the river course of the Hai system at the point where the rivers debouch on to the alluvial plain, except in swampy areas totalling 10,000 sq. km. (3,860 sq. mi.) which have been gradually silted up and have lost their flood detention capacity.

The total length of dikes of the Hai River system is 2,607 km. (1,630 mi.). They are constructed of earth and were first built mainly during the Tsing dynasty, particularly from 1662 to 1792, when Peking was selected as the capital of China.

The average annual rainfall in the basin is 518.9 mm. (20.4 in.) on the plain and 423 mm. (16.8 in.) in the upper basin with a mean value of 473 mm. (18.6 in.). The monthly distribution is very uneven with approximately 70 per cent falling in July and August. This is due mainly to heat convection, weak frontal lifting and convergence within occasional cyclones. The highest recorded rainfall during a storm of two days' duration from 23 to 24 July 1922 (at Tzechingkuan) was 578 mm. (21.6 in.) and that of 15 to 16 July 1924 (at Linminkuan) was 595 mm. (23.4 in.). The yearly variation of annual rainfall is also considerable. The ratio of wet to dry years is 4.14 at the Peking station.

Following the concentration of heavy precipitation from July to August, the discharge of the river, which has a comparatively small drainage area and short water course, varies considerably. High floods occur immediately after heavy downpours while during the height of the dry season a number of small tributaries practically dry up. The ratio between maximum and minimum flow, as a general rule, is 1,000 and over and the maximum for Yungting River reaches 6,250.

As the headwater area is covered with loess, the maximum silt content of the Yungting River, measured at Lukouchiao, where the dikes begin, reaches 55.73 % by weight and the annual silt run-off of the same river is estimated to be 42 million tons (23 million cu. m. or 22,700 ac. ft.). In fact the Hai River system possesses all the characteristics of a heavy silt-laden river, like the Yellow River, only on a smaller scale.

The alluvial plain is thickly populated with a density of 430 per square kilometre and is extensively cultivated, except for the saline strip along the coast and the swampy regions of the interior. Wheat, kaoliang, sweet corn and cotton are the chief crops. Here the common practice is to plant wheat or barley in the winter and kaoliang, soya beans, millet, corn or sweet potatoes in summer. Crops are harvested three times in two years.

Floods and Flood Damage

Torrential flow, not only in their headwaters, but also along the diked sections of the alluvial plain, is a characteristic of the rivers of the Hai River system. It often happens that the discharge increases during heavy storms from a few c.m.s. to a thousand c.m.s. within a few hours. As the silt load is high and requires a steeper gradient to carry the heavy suspensions, the diked course on the plain is quite steep. For example the average gradient of the Yungting Ho, starting from the diked section to the junction of the Peiyun, is 1:3,500, as compared with 1:37,000 of the Huai River and 1:50,000 of the Yangtze River on the alluvial plain. Therefore, the current is swift not only in the headwater, but also in the diked sections. As the river bed material is composed of deposits of very fine grain loess, less than a millimetre in diameter, and dikes are also constructed of the same material, erosion of the river bed generally results in the deviation of the main current to the dikes. Moreover the fan-shaped tributaries converging on a single water course which, at present, is inadequate to discharge the combined flood flow to the sea, further aggravates the flood problem.

Further, the river bed of the Tatsing River has seriously deteriorated following construction of a diversion dike above Lukouchiao on the Yungting River by the Japanese during the last war. The excessive diversion of the flood flow of the Yungting to

the Peikou River, designed to relieve flooding of a dike breach downstream, has resulted in serious silting of the Peikou River as well as of the Tatsing River proper. It was reported in 1943 that heavy silting took place of the river bed of the Peikou ranging from 2 to 3 m. (6.5 to 10 ft.). The upper course of the Tatsing River experienced similar deterioration.

Six major floods caused damage in recent years — 1912, 1916, 1917, 1924, 1929 and 1939. The last was, by far, the worst on record. Except for the 1939 flood all were caused by dike breaches in the Yungting River, usually along its southern main dike. Areas subjected to inundation in recent floods are shown in figure 13.

The flood of 1924 caused a dike breach on the southern bank of the Yungting River, and overtopping of the dikes of the Tatsing River. The flood flow inundated the areas between Yungting River and Tatsing River as well as the depressions between Tatsing River and the Tze-ya River. The total area inundated on this occasion was 5,500 sq. km. (2,120 sq. mi.).

The flood of 1929 also caused a dike breach on the southern bank of the Yungting River similar to that of 1924. The area inundated then was 3,000 sq. km. (1,160 sq. mi.).

The flood of 1939, which occurred during the war in China, was the most serious of the more recent ones. A breach along the southern bank of the Hai River led to inundation of the city of Tientsin. Overtopping and breaches of dikes occurred in many places along the Tatsing, Tze-ya and Nanyun Rivers. The total area inundated amounted to 12,200 sq. km (4,700 sq. mi.).

Considering the total area inundated by floods over a period of 22 years from 1918 to 1939 inclusive, the average annual inundated area works out at 2,330 sq. km. (900 sq. mi.). No detailed statistics on flood damage are, however, available. If the value of unit damage of the Yellow River plain of CNC \$ 21,804 per sq. km. is taken as a basis to estimate the flood damage of the North China plain, since the general economic conditions of the two areas are similar, the average annual flood damage of the Hai River system would amount to CNC \$ 50,700,000 or roughly US \$ 15 million, at prewar values.

Proposed Plan of Flood Control

Yungting River Flood Control Project.

The flood control scheme of the Yungting River was worked out by the Chili River Commission in 1925, and was revised by the North China River Commission in 1929. Construction work on part of the scheme was started in 1935, suspended when the

Sino-Japanese war broke out two years later, and resumed after the second World war, in 1948. The flood control and other development projects consisted of the following with the Kuan Ting detention reservoir as the principal flood control measure :

(1) Detention of the flood flow of Yungting River by a detention reservoir at Kuanting with a capacity of 460 million cu. m. (373,000 ac. ft.) to reduce the flood flow from 5,000 c.m.s. (176,600 c.f.s.) to 2,500 c.m.s. (88,000 c.f.s.). The height of the dam will be 30 m. (98 ft.). Another detention reservoir is to be constructed downstream of the first one at Taitzemou with a capacity of 225,000 cu. m. (184 ac. ft.).

(2) Construction of a diversion weir at Lukou-chiao to divert a part of the reduced flood flow to the Peikou River, thence to the Tatsing River.

(3) Improvement of the existing dikes.

(4) Training of the main river and dredging of the Peiyun River below Yungting River and the Chinchung River, a subsidiary channel leading to the sea.

(5) Reclamation and silt disposal work along a section of the river in the depressions outside the main dike as indicated in Figure 13.

(6) Construction of numerous check dams to prevent soil erosion on the upper tributaries.

The total cost of the project is estimated at CNC \$ 29,000,000 (1937 value) or roughly the equivalent of US \$ 8,760,000.

The Tatsing Flood Control Project.

On account of the lack of suitable sites for flood detention reservoirs, the flood control scheme has been confined mainly to embankments, river training and flood escape channels. The scheme is summarized below :

(1) Improvement of the existing dike system. Existing dikes were strengthened by the North China River Commission before the war and the work was continued by the Provincial Bureau of Reconstruction during 1943. A free board of 1 metre above the highest flood is provided for all dikes. Constant strengthening and improvement is still considered necessary.

(2) New channels, to correct the alignment of the existing river course, are proposed in some stretches, in order to facilitate the flood flow.

(3) Tu Lui flood escape channel. The inadequacy of the Hai River to carry the combined flood flow of the river system is to be met by dredging a new channel which will conduct part of the flood flow to the Gulf of Pohai. The new channel, designed to take off from the lower course of the Tatsing River, would have a total length of 49.3 km. (30.8 mi.), an average bottom width of 600 m. (1,970 ft.) in the upper part, and 160 m. (526 ft.) in the lower part, an average depth of 4 m. (13 ft.).

This channel is designed for a maximum capacity of 2,000 c.m.s. (71,000 c.f.s.) of which 800 c.m.s. (28,200 c.f.s.) is to be diverted again into the lower course of the Hai River, while the rest is to be discharged into the Machang River, which flows into the gulf. Construction work was commenced in 1940. Up

to 1948 excavation completed amounted to 5 million cu. m. and embankments completed amounted to 4.2 million cu. m. The former is 31 per cent of the proposed quantity while the latter comprises 37 per cent of the total.

HUAI RIVER

Summary of basic data

Total drainage area of Grand Huai River system	270,000 sq. km.	104,000 sq. mi.
Huai River	166,110 sq. km.	64,000 sq. mi.
Shu River	11,133 sq. km.	4,280 sq. mi.
Yi River	17,325 sq. km.	6,680 sq. mi.
Total length of Huai River (from source to outlet of Hung Tze Lake)	740 km.	460 mi.
Total length of dikes of Grand-Huai River system	2,400 km.	1,500 mi.
Total length of dikes of Huai River		450 mi.
Grand Canal		410 mi.
Shu River	460 k	290 mi.
Yi River		360 mi.
River slope Huai River (from junction of Ti River to Hung Tze Lake)	1 in 37,000	
Average annual precipitation of river basin	770 mm.	30 in.
Maximum flood discharge	15,000 c.m.s.	530,000 c.f.s.
Average annual discharge (at Fushan)	510 c.m.s.	18,000 c.f.s.
Minimum discharge (at Fushan)	20 c.m.s.	700 c.f.s.
Maximum flood volume (above base flow 6,000 c.m.s.) . .	14,360,000,000 cu. m.	11,600,000 ac.ft.
Maximum annual run-off (at Fushan)	34,721,000,000 cu. m.	28,200,000 ac. ft.
Mean annual run-off (at Fushan)	16,064,000,000 cu. m.	13,100,000 ac. ft.
Average annual run-off per square kilometre above Fushan	.00345 c.m.s./sq. km.	c.f.s. sq. mi.

General Features of the River Basin

The Huai River (see figure 14) lies between the Yellow River to the north and the Yangtze River to the south. Running from the north to the south, the Grand Canal crosses the Huai River and connects the Yellow and the Yangtze Rivers. East of the Grand Canal are the Yi and the Shu Rivers. The Grand Huai River system embraces these four water courses with a total watershed area estimated at about 270,000 sq. km. (104,000 sq. mi.), spreading over large areas in the provinces of Kiangsu, Shantung, Anhwei and Honan.

The length of the Huai River, measured from the river source in the Tungpai mountains to its outlet in Hungtze Lake, is approximately 740 km. (460 mi.), and the drainage area is 166,110 sq. km. (64,000

sq. mi). The drainage area for the Yi River is 17,325 sq. km. (6,680 sq. mi.) and for the Shu River 11,133 sq. km. (4,280 sq. mi.).

As to the general topography of the basin, the parts to the north-east and south-west are mostly mountainous districts, that to the north-west is hilly, and the central and the south-eastern parts comprise considerable area of level ground. The south-eastern portion, through which the upper Huai runs, has a relatively steep surface slope, but below the upper Huai the ground is flat. The Huai River basin has for long been a principal agricultural district of China. Rice, wheat, beans, corn, peanuts, sesame seeds and cotton are the main products. The Lishaho district (the district in northern Kiangsu east of the Grand Canal, south of the old Yellow River and west of Chung-Chang Ho) is especially noted for its rice pro-

duction. The population of the Huai River basin is estimated at about 58 million, approximately one-eighth of China's total population, and for this reason the development of the Huai River basin greatly affects the economic condition of the country as a whole.

Rising in the Tungpai Mountain on the southwest of the river basin, the Huai River runs eastward, and is joined by many tributaries as the Yin River, Kwen River and others in Honan and Anhwei Provinces, and then empties into Hungtze Lake. Issuing from the lake it divides into two courses, the San River and the Changfu River and empties mainly into the Yangtze River with a small portion entering the Yellow Sea separately. It is interesting to note that the Huai River possessed its own outlet to the sea until the Soong dynasty, during the Thirteenth Century, when the Yellow River burst its banks in Honan Province and usurped the discharge channel of the Huai River, whereupon the waters of the latter were forced to accumulate in Hungtze Lake and to find other means of escape. The Yellow River subsequently changed its course again in a north-easterly direction near Kaifeng in 1852, but the original lower course of the Huai had been silted up by the sediment of the Yellow River, and the Huai River has been unable to regain its original route to the sea.

At present, the Huai River, using Hungtze Lake as a detention reservoir, discharges most of its flood water from the lake through the San Ho and Kaopao Lakes, and finally through several leading channels into the Yangtze River.

The Yi River and Shu River, which join the Grand Canal in the east, have their sources in the Tai mountain system of the north. The Shu River which runs parallel to the Yi River, splits into two branches on the plain, one joining the Grand Canal and the other discharging directly into the Yellow Sea. The two rivers — Yi and Shu — are interconnected by branch watercourses.

When the Yi River has a very large flood, a part of the flood flow enters the Shu River, and the position is reversed when the Shu River flood is higher than that of the Yi River. In the event of floods of both rivers occurring simultaneously the areas adjoining the lower course of the Shu River would be severely affected by inundation.

The Grand Canal in the Huai region may be divided into three parts; the section between the Yellow River and the crossing of the Tientsin-Nanking railway near the Waishan Lake is the southern Shantung Canal; the middle portion extends southward to the vicinity of Hungtze Lake and is called the middle Grand Canal; while the part southward to the Yangtze River is known as the inner Grand Canal. The southern Shantung Canal and the middle Grand Canal are the principal channels for discharging the flood water of the Wen River, Sze River and other small streams in southern Shantung

Province, while Waishan Lake functions as a detention basin for the waters of all these streams.

Dikes exist on the lower courses of the Huai, Shu and Yi Rivers in the alluvial plain and along the Grand Canal connecting the Yellow River with the Yangtze. Except in some localities where the river flows along a higher bank on one side, or passes through a lake, dikes are usually constructed on both banks. The total length of the main dikes along the lower course of the Huai River is around 720 km. (450 mi.); along the Grand Canal of the Huai region, 660 km. (410 mi.); along the Shu River, 460 km. (290 mi.); and along the Yi River, 580 km. (360 mi.); making a total length of over 2,400 km. (1,500 mi.).

The mean annual precipitation in the Huai region is around 770 mm. (30 in.). The maximum on record is 1,180 mm. (46.4 in.) and the minimum only 490 mm. (19.2 in.). Owing to the influence of typhoons from the Pacific Ocean, rainfall in this area in June, July and August is especially heavy.

The dry season of the region is generally from October to February, and rainfall during these months is scanty. As rainfall is the source of stream flow, water levels and discharges of rivers in this region vary with the amount of precipitation over the watershed areas. For all these rivers, water levels are highest and discharges greatest during the months of June, July and August. After September the water level gradually drops with decreasing discharges till March of the following year when the cycle begins again.

Floods and Flood Damage

The main cause of floods of the Huai River is heavy precipitation in the fan-shaped drainage area, which has numerous streams connecting with the Huai, the river channel of which is inadequate to discharge the maximum flow.

June, July and August comprise the rainy season in the Huai basin with the rainy period generally extending over 15 days a month. The maximum monthly precipitation over the region is 300 to 700 mm. (12 to 27.5 in.) with a mean of 400 mm. (15.8 in.) while the maximum daily precipitation reaches as high as 200 mm. (7.9 in.). As the general topography of the lower Huai is very flat, and its tributaries are so numerous, it does happen that, in periods of prolonged rainfall, the flood flow of the tributaries discharges into the Huai simultaneously.

Before the initiation of the regulation scheme of the Huai River in 1934, the existing local dikes, scattered in different places, were not strong enough to withstand the flood flow, and the channel was capable of discharging only half of the flood flow with the result that vast areas were inundated.

Below Hungtze Lake, the discharge capacity of the outlet leading to the Grand Canal is small. The other channel conducting the flow from the Hungtze

through Kaopao Lake south to the Yangtze is also inadequate to discharge the flood flow. Inundation of the area around the lake is common. The Grand Canal itself discharges the flood of the Shu, Yi and many other smaller streams in the north. Flood escapes exist along the eastern dike of the Canal to discharge excess flow through small channels leading to the sea. These are again found inadequate to carry the flow. Dike breaches along the Grand Canal, in consequence, are not infrequent.

Since the Yellow River changed its course in 1852 and caused the complete silting up of the lower course of the Huai River, up to 1935 major floods causing serious damage occurred in 1860, 1866, 1870, 1873, 1883, 1897, 1906, 1909, 1910, 1916, 1921, 1926 and 1931, or approximately once in every six and a half years. Of these 13 floods within 84 years, 7 are classified as ordinary floods, 5 as high floods and 1 as an extraordinary high flood which is the one that occurred in 1931, together with that of the Yangtze.

Detailed data of flood damage is available for floods since 1911 and is given in the following table:

*Flood damage of the Huai River.
(Not including Grand Canal)*

Classification of flood	Year	Population affected by flood	Area of farmland inundated in hectares	Total loss in \$ CNC (pre war)
Ordinary	1916	3,009,000	1,450,000	93,499,000
Ordinary	1926	3,130,000	1,210,000	92,097,000
Mean		3,069,500	1,330,000	92,798,000
High	1921	7,693,000	3,320,000	215,163,000
Extraordinary	1931	20,025,000	5,180,000	564,231,000

Assuming the damage caused by the previous floods to be similar to that given above, the average annual flood damage from 1852 to 1935 inclusive, over a period of 84 years, is worked out as follows:

	Population affected by flood	Area of farmland inundated in hectares	Damage in \$ CNC (pre war)
7 ordinary floods	21,175,000	9,310,000	649,586,000
5 high floods	38,465,000	16,600,000	1,075,815,000
1 extraordinary high flood damage	20,025,000	5,180,000	564,231,000
Total damage of 84 years	79,665,000	31,090,000	2,289,632,000
Average annual damage	948,000	370,100	27,258,000

The average annual flood damage of the Huai amounts to CNC \$ 27,258,000 or roughly US \$ 8,260,000 based on the pre-war value of the CNC dollar. The average area of farmland inundated annually would be 370,000 hectares (910,000 ac.) with nearly one million people affected by floods.

Flood Problem and Flood Control Projects

The flood control project of the Grand-Huai system together with canalization of the Grand Canal and the development of irrigation was planned and executed by the Huai River Commission. The main feature of the project of flood control is utilization of the Hungtze Lake as a detention reservoir to regulate the outflow, and to provide an adequate flood channel leading the controlled flood flow separately to the Yangtze River and the Yellow Sea. The flood control part of the project consists of the following:

(1) Detention of flood flow in Hungtze Lake. Besides the existing dikes, additional dikes are to be constructed along the low-lying areas around the lake, to increase its capacity to 7,415 million cu. m. (6 million ac. ft.). A movable sluice is to be constructed at the outlet of the flood channel leading to the Yangtze, and another on the flood channel leading to the sea. The lake also acts as a storage for irrigation and navigation uses.

(2) Flood channels. The controlled flood flow is to be discharged by two separate flood channels leading to the Yangtze River and the Yellow Sea respectively. The maximum designed flood flow is 15,900 c.m.s. (530,000 c.f.s.) of which 6,000 c.m.s. (212,000 c.f.s.) discharges into the sea and the balance of 9,900 c.m.s. (318,000 c.f.s.) is to be diverted into the Yangtze. If floods of the Huai and Yangtze coincide, the flood flow of the Huai to the Yangtze is to be limited to 6,000 c.m.s. (212,000 c.f.s.).

(3) Construction and strengthening of dikes along the main tributaries of the Huai River above Hungtze Lake.

The total cost of the flood control project, including dikes, regulators, channel excavation, and river training works, is estimated at about CNC \$ 292,000,000 or the equivalent (at pre war value) of US \$ 85,000,000.

Flood Control Activities

The regulation scheme of the Grand Huai River System was commenced before the Second World War. Dikes along the main river as well as along its tributaries were strengthened and repaired. The regulator, as well as the new channel leading the flood flow to the sea and many shiplocks on the Grand Canal, were completed before the war. When the Yellow River shifted its course in 1938 during the war and flowed into the Huai River, thereby greatly increasing the latter's flood flow, many dikes were washed away. Regulators and shiplocks suffered heavy damage.

Rehabilitation of the dikes and other flood control works were undertaken after the war, but have not yet been completed.

INDUS RIVER

Summary of basic data

Drainage area and length of river

	Drainage area in hills (excluding the plain)		Length of river	
Total of Indus system	452,000 sq. km.	174,500 sq. mi.		
Indus main river (a)	306,000 sq. km.	118,000 sq. mi.	3,293 km.	2,056 mi.
Sutlej	61,000 sq. km.	23,400 sq. mi.	1,630 km.	1,012 mi.
Beas	13,920 sq. km.	5,384 sq. mi.	446 km.	278 mi.
Ravi	9,230 sq. km.	3,562 sq. mi.	1,059 km.	658 mi.
Chenab	29,500 sq. km.	11,399 sq. mi.	1,361 km.	847 mi.
Jhelum	32,200 sq. km.	12,445 sq. mi.	895 km.	556 mi.
Kabul	90,500 sq. km.	35,000 sq. mi.		
Shyok	33,600 sq. km.	13,000 sq. mi.		
Gilgit	25,900 sq. km.	10,000 sq. mi.		
Zaskar	25,900 sq. km.	10,000 sq. mi.		
Singghi	18,100 sq. km.	7,000 sq. mi.		
Dras	12,950 sq. km.	5,000 sq. mi.		
Shingar	12,950 sq. km.	5,000 sq. mi.		

Precipitation over the hill catchment (average from 1900 to 1939).

	Summer		Winter		Annual	
Indus	218 mm.	8.6 in.	215 mm.	8.4 in.	431 mm.	17.0 in.
Sutlej	292 mm.	11.5 in.	188 mm.	7.4 in.	480 mm.	18.9 in.
Beas	1,100 mm.	43.1 in.	335 mm.	13.2 in.	1,435 mm.	56.3 in.
Ravi	880 mm.	34.7 in.	475 mm.	18.7 in.	1,355 mm.	53.4 in.
Chenab	770 mm.	30.3 in.	470 mm.	18.5 in.	1,240 mm.	48.8 in.
Jhelum	580 mm.	22.9 in.	530 mm.	20.9 in.	1,110 mm.	43.8 in.

Maximum and minimum discharges

	Maximum discharge		Minimum discharge	
Indus at Kalabagh	26,000 c.m.s. (1942)	917,015 c.f.s.	490 c.m.s.	17,304 c.f.s.
Sutlej at Rupar	13,900 c.m.s. (1947)	490,242 c.f.s.	78 c.m.s.	2,773 c.f.s.
Beas at Dera Gopipur	9,800 c.m.s. (1942)	346,223 c.f.s.	60 c.m.s.	2,130 c.f.s.
Ravi at Madhopur	7,350 c.m.s. (1900)	260,000 c.f.s.	34 c.m.s.	1,216 c.f.s.
Chenab at Merala	20,350 c.m.s. (1929)	718,000 c.f.s.	102 c.m.s.	3,618 c.f.s.
Jhelum at Mangla	21,540 c.m.s. (1929)	760,000 c.f.s.	112 c.m.s.	3,943 c.f.s.

a/ Drainage area of Indus main river includes the Kabul, Shyok, Gilgit, Zaskar, Singghi, Dras and Shingar rivers

General Features of the River Basin

The Indus River, rises in Tibet, in the trough lying between the Kailas and the Ladakh ranges, at a height of about 5,200 m. (17,000 ft.). After a course of nearly 320 km. (200 mi.), it crosses the south eastern boundary of Kashmir at an elevation of 4,200 m. (13,800 ft.). From the Kashmir frontier to Leh, the capital of Ladakh, is 200 km. (125 mi.) and the river reaches an elevation of 3,210 m. (10,500 ft.). A little below Leh, the Indus receives the Zaskar, which drains the south-east of Kashmir. About 240 km. (150 mi.) down-stream of this point, just above Skardu, a large tributary, the Shyok, flows in from the east at an elevation of 2,450 m. (8,000 ft.). Further down, the Indus is joined by the Gilgit river and here the bed is about 1,220 m. (4,000 ft.) above sea level. It then crosses the Kashmir border and takes an almost right angle turn into the North Western Frontier Province of West Pakistan. The river then flows between low hills in a narrow and deep channel receiving an important tributary, the Kabul

river on the west. The Indus emerges from the hills at Kalabagh about 5 km. (3 mi.) upstream of the Barrage of that name and 80 km. (50 mi.) downstream of Kalabagh it receives the Kurram river from the west. It then spreads out on a wide plain often dividing into two or more channels, swinging from one side to the other. During floods it is sometimes over 16 km. (10 mi.) wide and heavily erodes its banks. The erosion caused is sometimes very severe and during the thirties the town of Dera Ghazi Khan was gradually washed away and a new town had to be built at a site outside the river's domain.

Before reaching Sind, the Indus is joined at Mithankot by its most important tributary, the Panjnad river, which carries the waters of the well known 5 rivers of the Punjab (five waters) namely the Sutlej, Beas, Ravi, Chenab and Jhelum, from which the Province derives its name. Lower down in Sind, the main channel of the river continues to swing backwards and forwards over a wide belt, the swing varying from 6.4 km. (4 mi.) near the Sind border to as much as 19 km. (12 mi.) upstream of the Sukkur

Barrage, sometimes causing severe erosion necessitating retirement of banks. Downstream of the barrage, for a length of about 32 km. (20 mi.), the swing varies from 6.4 to 9.7 km. (4 to 6 mi.), but further down, the river gradually narrows as it loses its erosive power due to flatter slopes, till at Kotri it does not vary appreciably and is restricted to a width of 800 m. (0.5 mi.). Below Kotri, it remains much narrower than above it, and finally falls into the Arabian Sea in two main branches, the Ochito and the Hydri rivers, about 100 to 120 km. (60 to 80 mi.) south-east of the Port of Karachi, the capital of Pakistan.

The lower Indus is an alluvial river, which has been gradually building up its bed on a flood plain of its own making and from Mithankot to the sea the country slopes away from the river on both banks which are embanked.

The characteristics of the catchment basins of the upper hill tributaries of the Indus vary as much as those of its own catchment basin as a whole from those of the five Punjab rivers. The summer rainfall varies from 47 mm. (1.86 in.) at Leh to 1,030 mm. (40.70 in.) at Murree. Winter rainfall varies from 33 mm. (1.3 in.) at Leh to 560 mm. (22 in.) at Oghi. The range of temperature variation is similar. The lofty ranges of the great Himalayas interpose an almost insurmountable barrier between the monsoon winds and the trans-Himalayan zone of the Indus catchment. In this zone, the rainfall is extraordinarily small. The air is intensely dry and clear; the daily and seasonal range of temperature is extreme. The mean temperature varies from about 15°F. in January to about 64°F. in July. The daily range is about 25°F. But these figures give no idea of the rigours of the severe climate. Rocks exposed to the sun may be too hot to touch and at the same time it may be freezing in the shade. In the western parts of the Indus catchment the winter rainfall is greater than the summer rainfall. Kabul records a rainfall of 203 mm. (8 in.) in winter against 114 mm. (4.5 in.) in summer.

As stated above, the most important tributary of the Indus is the Panjnad River, which carries the waters of the five Punjab rivers, namely Sutlej, Beas, Ravi, Chenab and Jhelum. The Sutlej and the Beas rivers join at Harike above Ferozepore in India and the combined stream, known by the name of Sutlej, joins the Chenab at Panjnad. The Jhelum joins the Chenab near Jhang, and the Ravi joins this combined stream about 48 km. (30 mi.) above Multan.

The characteristics of the catchment basins of the five Punjab rivers are described briefly below :

Sutlej.

The mountain basin of this river lies mainly north of the Himalayas, and the area of the Himalaya proper drained by it between the great range and the plains consists of an insignificant strip.

This river rises in the distant highlands of Tibet and has a very long course through the mountains.

The trans-Himalayan portions of its basin receive comparatively little rain, but possibly greater than similar portions of the basin of the Indus proper. The watershed between the Sutlej and the Indus in Nari Khorsam, a province of Tibet, is the Ladakh range with peaks of 5,800 to 6,100 m. (19,000 to 20,000 ft.).

The Sutlej emerges from the Sivalik hills at the Bhakra gorge and flows in a narrow deep stream with low hills on either side for about 16 km. (10 mi.) before it widens into an alluvial river. Its bed material gradually changes from boulders at Bhakra to sand at Rupar, 80 km. (50 mi.), downstream.

The fall of the Sutlej from its source to Bilaspur is fairly uniform and averages about 1:150 to 1:176; the height of its bed is 4,600 m. (15,000 ft.) near Rakas Lake and 3,350 m. (1,100 ft.) at Bilaspur, 64 km. (40 mi.) above Bhakra. The slope gradually flattens to 1:5,000 or even less in the plains below Rupar.

In a normal year the monsoon months are June, July and August. The rain comes in bursts with longer or shorter breaks between. About the third week of September the rains often cease. From October to December there is generally little rain. In January and February snow falls and there is some rain in the plains also. The really heavy falls of snow occur at levels much higher than Simla (2,150 m. or 7,000 ft.).

Summer rainfall recorded at Simla and Kasauli are 1,340 and 1,420 mm. (52.7 and 56.2 in.) respectively, but they are not at all representative of the catchment as a whole. Kilba higher up records only 435 mm. (17.2 in.) and Poo 123 mm. (5.03 in.). During winter, rainfall varies from 218 mm. (8.6 in.) at Poo to 414 mm. (16.3 in.) at Nichar. It, therefore, appears that the trans-Himalayan region of the Sutlej gets more precipitation in winter than in summer.

Beas.

The Beas rises in the Pir Panjal Range at the Rohtang pass at a height of about 1,900 m. (13,000 ft.). Its several affluents combine to pierce the Dhauladhar range at Larji, just below Mandi. In the 120 km. (75 mi.) from its source to Larji, its gradient averages 1:42, but below Larji the gradient rapidly decreases and in the valleys of the outer Himalayas is hardly more than 1:528, gradually flattening to about 1:5,000 in the plains. The catchment area of the Beas is thickly wooded.

Beas records the heaviest rainfall in the Punjab Himalayas. Dharamsala Lower (1,390 m. or 4,552 ft.) gets 2,650 mm. (104.4 in.) and Palampur (1,270 m. or 4,150 ft.) records 2,300 mm. (90.8 in.) during summer. The lowest summer rainfall in the catchment is 582 mm. (23 in.) at Kulu. The winter rainfall varies from 228 mm. (9 in.) at Hamirpur (734 m. or 2,406 ft.) to 508 mm. (20 in.) at Nagar.

Ravi.

The Ravi has the smallest catchment of the Punjab rivers. It rises near the Rohtang pass in

Kangra and drains the southern slopes of the Pir Panjal and the northern slopes of the Dhauladhar. Near the town of Chamba it runs as a swift slaty-blue mountain stream. It leaves the Himalayas at Bisolee and, after crossing the Sivaliks, it enters the Punjab plain below Madhopur, the headwaters of the Upper Bari Doab Canal.

Summer rainfall over the hilly catchment is fairly uniform with the exception of Dalhousie. Situated at a height of about 2,140 m. (7,000 ft.), Dalhousie enjoys a mean summer rainfall of 1,780 mm. (70 in.) while in the rest of the catchment the variation is only from 634 mm. (25 in.) at Tissa (1,530 m. or 5,000 ft.) to 1,200 mm. (47 in.) at Bisolee. Winter rainfall varies from 170 mm. (6.7 in.) at Pathankot (460 m. or 1,500 ft.) to 1,200 mm. (27 in.) at Tissa. Rainfall in the plains gradually decreases in the direction further away from the mountains, as already stated for the Sutlej, the average annual rainfall being about 760 mm. (30 in.) in the sub-mountainous area decreasing to about 254 mm. (10 in.) near Multan.

Chenab.

Being the biggest of the five Punjab rivers, the Chenab has two main upper streams, the Chandra and the Bhaga and the river below their junction is called by their joint name, the Chandra-Bhaga, in its upper course. These streams rise on opposite sides of the Baralacha pass (4,880 m. or 16,047 ft.). The slope of the Bhaga is 1:35, twice that of the Chandra. The Chandra is from its commencement a stream of some size and has the appearance of a river at Khoksar (3,350 m. or 11,000 ft.). It passes through a totally barren land, where there are no signs of life, and solemn mountains clad in eternal snow lie on its flanks. No villages adorn its banks, there is little attempt at cultivation, human habitations are scarce and far apart and nothing greets the eye but the never ending and monotonous cliffs. From the junction of these two tributaries for a distance of over 150 km. (100 mi.), the valley of the river is formed by the great Himalayan and the Pir Panjal ranges. The river makes a great bend at Kishtwar, where it escapes through the Pir Panjal by a gorge. The mountains around are rocky below and have wooden slopes above. Below Kishtwar, it runs in a south-westerly direction and after crossing the upper and lower Sivalik hills enters the plain above Merala, the headworks of the upper Chenab canal. Summer rainfall in Chenab mountain catchment varies from 280 mm. (11 in.) at Kaylong (3,150 m. or 10,388 ft.) to 1,280 mm. (50.6 in.) at Ramnagar (750 m. or 2,450 ft.). Winter rainfall varies from 170 mm. (6.7 in.) near Jaimu (305 m. or 1,000 ft.) to 653 mm. (25.7 in.) at Gulabgarh (3,050 m. or 10,000 ft.). The rainfall gradually decreases as we go down the plain as in other river catchments.

Jhelum.

The Jhelum rises from a large spring at Virnag at the upper end of the famous valley of Kashmir.

The upper basin of the Jhelum forms part of the trough between the great Himalayan and the Pir Panjal ranges. This valley is of oval shape, its long diameter lying parallel to the general direction of the ranges. From crest to crest the transverse ridges on the south-east and north-west of the basin are about 190 km. (120 mi.) apart. On the north-east side, the peaks of the great Himalayas rise above 5,200 m. (17,000 ft.); on the south-west, the loftiest peaks of the Pir Panjal exceed 4,600 m. (15,000 ft.). Those of the two transverse ridges attain 3,960 m. (13,000 ft.). The height of the valley above sea level varies from 1,590 to 1,830 m. (5,200 to 6,000 ft.).

Through the valley of Kashmir the river is rather flat and passes through the town of Srinagar and the Wooller Lake. At Baramula (1,540 m. or 5,040 ft.), where its course through the flat open valley terminates, the river rushes through a narrow chasm in the rocks and entirely changes from a placid stream to a raging torrent. At Uri the river takes a bend and follows the direction of the range to Muzaffarabad where it is joined by its main tributary, the Kishenganga. From Baramula (1,560 m. or 5,100 ft.) to Muzaffarabad (752 m. or 2,470 ft.) the distance is 120 km. (80 mi.) and the slope about 1:160. From Muzaffarabad to the plains at Mangla the slope of the Jhelum is 1:252. Lower down it flattens to 1:5,000 and less, like the other Punjab rivers in the plains, according to the general slope of the country through which they flow.

Summer rainfall in the hilly catchment varies from 305 mm. (12 in.) at Badgaon (1,600 m. or 5,232 ft.) to 990 mm. (39 in.) at Punch (980 m. or 3,210 ft.), while the winter rainfall varies from 214 mm. (8.4 in.) at Mirpur (610 m. or 2,000 ft.) to 1,110 mm. (43.6 in.) at Sonamarg (4,400 m. or 14,450 ft.).

The dike system of the Indus is as follows:

Upstream of all diversion dams on the main river as well as on the tributaries, the river is double embanked to prevent flooding of the lands on both sides and outflanking of the barrages, and all these embankments are very efficiently maintained and carefully protected, in some places by spur dikes armoured with stone or longitudinal stone revetment. Elsewhere there are local embankments here and there at vulnerable points. Embankments on both sides of the lower Indus start opposite Kashmir and continue practically down to the sea.

The only embankments in existence prior to the great flood of 1861 were village bunds. These were improved and new ones constructed in 1875, 1878 and 1887. Many bunds were also built in the nineties of the last century, and the remaining gaps were mostly closed during the construction of the Sukkur Barrage canals in the thirties.

As a general rule the embankment section is 3.65 m. (12 ft.) wide at top, with side slopes of 1:3 on both sides, and a free board of 1.8 m. (6 ft.).

In Sind the designed width of bank used to be 2.4 m. (8 ft.), but was widened to 3.65 m. (12 ft.) to provide a motorable road, by steepening the side slopes above the H.F.L. from 1:3 to 1:1.5. The side slopes of the Indus embankments in Sind vary from 1:3 to 1:4 on the river side and are 1:3 on the land side. A berm, or horizontal ledge, is also provided on the land side so as to cover a hydraulic gradient of 1:6. According to the typical cross sections, this berm is 3.05 m. (10 ft.) wide and 0.9 m. (3 ft.) high for embankments more than 2.4 m. (8 ft.) above ground; and 4.6 m. (15 ft.) wide and 1.2 m. (4 ft.) high for those over 3.35 m. (11 ft.) above ground level. In bed soil, a double bank is provided with a channel in between for moistening the soil by pumping water into this channel before the arrival of floods, while in exceptionally poor soil, a sand or masonry core is also provided.

Almost the entire low water flow of the Indus and its tributaries is being utilized for irrigation through canals; and diversion dams have been constructed at the following sites for this purpose:

- The Indus at Kalabagh and Sukkur.
- The Sutlej at Nangal and Ferozepore in India; at Suleimanki and Islam in Pakistan.
- The Ravi at Madhopur in India; at Balloki and Sidhnai in Pakistan.
- The Chenab at Merali, Khanki, Trimmu and Panjnad.
- The Jhelum at Rasul. The upper Jhelum canal takes off at Mangla, just above a natural shingle bar.

Floods and Flood Damage

The basic cause of floods on the Indus plain is that the lower course of the Indus is an alluvial river which has built up its bed on a flood plain of its own making and the country slopes away from the river on both banks. The quantity of silt carried by the Indus is very great, and were there no counteracting influences at work, the delta would be extending seawards much more rapidly than it has done. There is, however, evidence to show that since the days of the town of Mohan-jo-Daro, some 5,000 years ago, the rise of water level has been some 9 m. (30 ft.). According to Inglis, if this rise were translated into terms of riverside rise (as the town is further away from the river), it would be at least double this figure and of the order of one foot a century. As a result of the enquiry into the causes of dike breaches in Sind carried out by Inglis⁽¹⁾ in 1942-43, he arrived at a number of conclusions, some of which are reproduced below:

(1) C.C. Inglis — *The Behaviour and Control of Rivers and Canals*, Research publication no 13, Government of India, Central Waterpower, Irrigation and Navigation Research Station, Poona (Yeravada Prison Press Poona 1949).

(1) It is inevitable that river flood levels will continue to rise — increasing the danger of breaches and the damage resulting therefrom. Consequently the margin of safety considered adequate for embankments before a barrage is built is not sufficient thereafter.

(2) Assuming Barrage regulation and river conditions to be similar to those upto the end of 1941, specific discharge gauges at Sukkur for a flood of 14,200 cms. (500,000 c.f.s.) are likely to rise 1.1 m. (3.5 ft.) above pre-Barrage levels by 1955 and 1.5 m. (5 ft.) by 1990.

(3) The heading up at Sukkur seems to have affected the Gauge 37 km. (23 mi.) upstream after 11 years, i. e. about 3 km. (2 mi.) a year.

The extent of damage caused by floods in the Indus and its tributaries in West Pakistan during 1948, as intimated by the Government of Pakistan is detailed below:

Punjab

Number of villages damaged	3,456
Number of villages destroyed	122
Loss of human life	150
Number of cattle lost	2,877
Number of houses damaged	91,502
Number houses destroyed . . .	67,000
Area of crops destroyed . . .	184,000 ha. (454,000 ac.)

Bahawalpur

There was very little damage, except to thatched huts between the river and the embankment. The cost of re-erecting such huts is said to be insignificant. There was no damage to crops. The only damage caused was side erosion, due to which valuable land was washed away, but no details of the area or price of such land are available.

Cultivated area flooded and destroyed	121,000 ha. (300,000 ac.)
Houses and huts destroyed.	20,000
People rendered homeless . . .	90,000

The total damage caused in West Pakistan from the 1948 flood was assessed at Rupees 135 million or U.S. \$ 40 million. Flood damage of this order generally occurs once in 40 years, but damage of slightly lesser intensity is not uncommon once every 4 or 5 years.

Flood Control Activities

The Departments of Irrigation in the different Provinces of West Pakistan look after flood control also, each Province and its various officers looking after the part of the river lying within their jurisdiction. There was little coordination between the various provinces before the partition with India, but

since the partition, the Central Engineering Authority of Pakistan has been entrusted with the responsibility to devise measures for controlling floods, development of hydro-electric schemes, promoting irrigation and furthering facilities to encourage inland navigation, where such works may be found to be economically practicable within the Dominion. In the Punjab a special division was opened in 1949 to deal with flood problems while in Sind this work is entrusted to the Indus River Commission, which is presided over by the Chief Engineer with the Superintending Engineers as members and the Executive Engineer of the Development and Research Division as its Secretary. The latter officer is also responsible for collecting all the data for the river.

The system of patrolling the bunds during the rising stages of the river is practised. Materials to deal with leaks or breaches are stored at all dangerous points to be readily available for emergencies. Where the danger is greatest extra precautions are taken to have more vigilant patrol. Special establishment is engaged during the flood season and patrolling is supervised by all officers right up to the Chief Engineer in Sind, especially in the critical stages of the high river.

The distance between the river edge and the embankment is kept under strict observation, particularly in places where erosion is active and the river is within a short distance of the embankment. Whenever there is active erosion and the river approaches dangerously close the embankment line and in any case when it is eroding within 460 m. (1,500 ft.) of the toe of the embankment, proposals for a retired embankment must be submitted by the officer in charge at the end of the monsoon and the work should be completed in good time to ensure its thorough wetting before the front embankment is eroded.

After the floods of 1948, the Government of Punjab (P) felt that immediate measures were necessary to safeguard life, property, lands and crops against this recurring evil and proposed construction of levees and opening of certain drainages estimated to cost Rs. 135 million (U. S. \$ 40 million), spreading the execution of the work over a number of years as funds became available. In Bahawalpur and Sind, flood control works are mainly of the nature of constructing and improving levees.

Regarding multipurpose projects, the following are contemplated on the Indus and its tributaries :

(1) The great Darbund Dam Project in the North West Frontier Province to harness the Indus River is under consideration by Pakistan. Its main features are to eliminate floods, produce power of the order of 1.6 million K. W., irrigate 815,000 ha. (2 million ac.) and provide controlled discharge to permit the development of inland navigation from Karachi to almost the foot of the Himalayas. The Dam will be 275 m. (900 ft.) high and will cost Rs. 2,000 million (U.S. \$ 600 million).

(2) The construction of an irrigation barrage at Kotri on the lower Indus has been started by the Pakistan Government at an estimated cost of Rs. 222 million (U.S. \$ 67 million). This scheme proposes to irrigate an area of nearly 815,000 ha. (2 million ac.) and is planned to be completed in 10 years. The provision of navigation facilities through a canal connecting Karachi with the Indus and generating 60,000 K.W. of hydro-cum-thermal power are also being examined.

(3) In India, the construction of the Bhakra and Nangal Dams and canals is in progress on the river Sutlej, a tributary of the Indus. The completion of the Bhakra dam should have an appreciable effect in lowering flood levels of the Indus.

IRRAWADDY RIVER

Summary of basic data

Total drainage area	415,000 sq. km.	160,500 sq. mi.
Area of delta below Prome	48,000 sq. km.	20,500 sq. mi.
Length of main river	2,000 km.	1,250 mi.
Average annual rainfall		
Upper basin	1,500 to 2,000 mm.	60 to 80 in.
Central zone	750 to 1,000 mm.	30 to 40 in.
Lower basin	2,000 to 2,500 mm.	80 to 100 in.
Length of embankments	1,300 km.	800 mi.
Area protected by embankments	4,050 sq. km.	1,560 sq. mi.
Maximum flood discharge (Saiktha, 1877)	64,000 c.m.s.	2,250,000 c.f.s.
Average annual discharge (Saiktha) ^(a)	13,400 c.m.s.	474,000 c.f.s.
Minimum discharge (Saiktha 1877)	1,306 c.m.s.	46,000 c.f.s.
Average annual run-off	524,000,000,000 cu. m.	425,000,000 ac.ft.
Annual silt run-off	291,000,000 tons	
Average annual run-off per unit area	0.04 c.m.s./sq.km.	3.66 c.f.s./sq.mi.

(a) According to Gordon's Report of Irrawaddy R. (1870-1879).

General Features of the River Basin

The Irrawaddy River (see figure 16), with a length of 2,000 km. (1,250 mi.) and catchment area of 415,000 sq. km. (160,500 sq. mi.) is the most important river in Burma from the economic point of view. The headwaters of this river, the Mali and N'Mai, rise in the mountains of Tibet. They join each other 40 km. (25 mi.) north of Myitkyina, and the Irrawaddy River flows south to the neighbourhood of Mandalay, from where it bears westward for a short distance and is joined by another of Burma's major rivers, the Chindwin, which comes out of the Hukawng Valley. The river then flows southward crossing the delta to the sea.

The Irrawaddy River basin is bounded on the west by the Naga Hills, Chin Hills and the Arakan Yomas whose ranges vary in height from 1,000 to 2,400 m. (3,300 to 8,000 ft.) above sea level and slope down toward the south to the alluvial plain before it reaches the coast. To the north are the mountains of Tibet. In the upper portion of the river to the east, the basin is bounded by the Shan plateau averaging some 1,000 m. (3,300 ft.) above sea level and lower down towards the coast the Irrawaddy is separated from the Sittang River by the wooded hills known as the Pegu Yomas, where the last escarpment forms the laterite ridge, at the southern extremity of which stands Rangoon, the capital of Burma.

In its upper reaches the Irrawaddy flows through hilly country, where the river has its source, and in the ravine-like passes the great teak trees push their way up through scrub jungle. The area is one of impenetrable brush with tangled creepers and clumps of bamboo. High hills, almost forest-covered to the summit, are to be found here. The rainfall varies from 1,500 to 2,000 mm. (60 to 80 in.) a year.

In its middle reaches the river flows through the broad Mandalay basin. Sheltered by the coastal ranges to the west this broad basin is known as the dry zone. It has an annual rainfall of only 750 to 1,000 mm. (30 to 40 in.). Stunted forest vegetation here contrasts with the evergreen and swamp trees of the lower coastal region. Drought is a danger to crops which not have the benefit of irrigation. There was a period of extreme scarcity of rainfall from 1807 to 1812.

From the Mandalay basin the Irrawaddy flows south till it reaches Prome in the river delta. Embankments start at Kyangin some 350 km. (220 mi.) from the coast. The river slope in the delta varies from 1:15,000 to 1:22,000. The width of the main channel (at Shweluang) is 730 m. (2,400 ft.) and the mean depth is 12 m. (40 ft.). The Irrawaddy, flowing through the delta at a distance of some 100 km (64 mi.) from the coast is broken up into numerous streams and creeks. Then it pours into the sea through nine large deltaic mouths.

The delta has a cultivated area of 2.85 million ha. (7 million ac.) with over 90 per cent under paddy, and before the war, it grew most of the rice, which enabled Burma to become the greatest rice-exporting country in the world. Practically all the silt suspended in the river is carried out to sea, where much of it is swept into the Gulf of Martaban. It is believed that the coast line at the mouth of the Irrawaddy River is advancing at a rate of 4.8 km. (3 mi.) in 100 years, which is equivalent to about 10 sq. km. (4 sq. mi.) of new deltaic land appearing annually. The extension of the delta seawards will not affect flood levels because the river, in cutting off loops, shortens its course. Thus, in 60 years, a shortening of 39 km. (24 mi.) has taken place.

Embankments comprise the chief method of flood control employed on the delta (see figure 16). The greater part of most productive land of the delta is protected by embankments which have been constructed by the Government from 1861 onwards. Private enterprise has followed this lead. The most important of the systems of privately-owned embankments was on the east bank of the Irrawaddy from Yandoon to Pyagyigon. It was later taken over by the Government, who re-sectioned the levees to accepted standards.

The total length of embankments on the Irrawaddy delta is about 1,300 km. (800 mi.) and the area protected is about 400,000 ha. (1,000,000 ac. (1)). The cost of construction of the main Irrawaddy embankments amounted to nearly Rs. 6,000,000. The protected lands are taxed about Rs. 1.5 per acre annually and, before the war, the net revenue from this source was about 15 % of the total capital investment.

The standard dimensions of the embankments are as follows :

Height	Top width	Side slope	
		River side	Land side
Less than 2.6 m. (8 ft.)	2.6 m. (8 ft.)	1:2	1:2
2.6 — 4.0 m. (8 — 12 ft.)	2.6 m. (8 ft.)	1:2-1/2	1:2
4.0 — 5.0 m. (12 — 15 ft.)	2.6 m. (8 ft.)	1:2-1/2	1:2-1/
5.0 — 6.5 m. (15 — 20 ft.)	3.3 m. (10 ft.)	1:3	1:4
6.5 — 8.3 m. (20 — 25 ft.)	3.3 m. (12 ft.)	1:3	1:4

The embankments are made of earth, which is ordinarily available in the immediate vicinity, where they are to be constructed. In most cases this is good loam, and the types of section provided have been found to be adequate.

Where the soil is largely sand, the slope on the land side is flattened to as much as 1:11. Where the soil is largely clay it is found that a shoulder or banquette is required in order to prevent slipping.

The embankment is built well in advance of the time when it will be required to withstand the pressure of flood waters. This usually allows at least one rainy season for the embankment to consolidate. The earth is laid in layers and a settlement allowance of three inches per foot is given. No artificial consolidation is done, but after being drenched with nearly 100 inches of rain (the normal annual rainfall) it is found that a good solid embankment has resulted. Where it is anticipated that an embankment would have to come up against flood waters shortly after completion, tamping rollers drawn by Caterpillar D 4 tractors are used for consolidation. This method of consolidation results in a very sound bank which shows no settlement after one rainy season.

Regarding bank protection work in the 800 km. (500 mi.) of Government-owned embankments, it is only in a few places that protection is necessary. No methods of indirect protection are resorted to. Such methods are considered very expensive, and yield no conclusive results. Embankments are not built at the very edge of the river, but a margin is left, the width of which varies with the locality. Where the river is eroding its banks, the amount of annual erosion is noted, and when it becomes apparent that the embankment will fall into the river in a couple of years, a retirement is built. This retirement is aligned at such a distance from the old alignment that it would take the river some years to threaten the retirement itself.

Protection against erosion of the embankment alone by wave wash is seldom necessary, because the margin of the river bank between the embankment and the river edge is frequently covered with tall grasses (kaing grass), which break the force of the waves. In some reaches, however, protection is necessary, and this is provided by dividing the reach concerned into compartments about 12 m. (40 ft.) long by means of bamboo stakes. These compartments are filled with floating weeds such as water hyacinths, for a width of from 4 to 6 m. (15 to 20 ft.) and provision is made for the floating weeds to remain in their compartments. The floating blanket is found adequate to absorb the erosive power of the waves. Positive protection in the shape of concrete slabs laid *in situ* has been provided in certain reaches, and is quite satisfactory. This method, however, is expensive and

because the river meanders, it may happen that after some years no protection will be needed at the site where such permanent protection is provided.

The silt content of the river measured at Henzada from 1877-78 gave an average value of 0.0508 %, varying from .022 to .104 % by weight. The average annual silt run-off from 1869-1877 was 291 million tons with a maximum of 352 millions tons (1875) and a minimum of 227 million tons (1876).

Early records of the Nineteenth Century show that there were four high floods in every ten years. In 1869, the embankments were designed to be 3 feet above the high floods of 1868, which at the time was considered so exceptionally great that no unusual precautions were considered necessary to be taken for a greater flood. The 1871 flood shook the faith in the notion considerably, when it rose nearly an average of one and a half feet above that of 1868. In 1875 there was still an excess of one foot rise over the previous known high flood. In 1877 a still higher flood occurred, rising at Saiktha to 0.57 m. (1.88 ft.) above the 1875 record.

The flood of 1868 which was looked upon as the highest flood ever known, was exceeded on no less than eleven occasions in the next 25 years, and in some cases by as much as 1.07 m. (3.5 ft.).

In 1939, there occurred in the Irrawaddy one of the biggest floods ever recorded. Available records show, that the flood of 1939 was the highest since 1877, or within a period of 62 years; but in 1947 a still higher flood was experienced over that of 1939 by 0.2 m. (0.65 ft.).

A study of the flood discharge for the last 80 years (1869 to 1949) shows that floods of considerable magnitude can be expected with the probable frequency at Saiktha given in the following table :

Probable occurrence once in	Flood discharge	
200 years	68,000	2,400,000
100 "	57,500	2,030,000
50 "	50,400	1,780,000
10 "	43,000	1,520,000
	40,800	1,440,000
	38,400	1,355,000

The discharge observations made at Saiktha during the flood of 1875 established the fact, that the peak discharge was 53,400 c.m.s. (1,823,600 c.f.s.). A discharge of 63,900 c.m.s. (2,250,000 c.f.s.) was deduced for the flood of 1877. Flood discharge measured at Chauk was 56,600 c.m.s. (2,000,000 c.f.s.) for the peak of the flood of 1939. From the available records of the previous floods, the only conclusion to draw is that a future flood may not only equal that of 1877 but may exceed it, and it is considered that a flood of 70,900 c.m.s. (2,500,000 c.f.s.) may not be beyond the bounds of possibility, because the very high flood of August 1939 was caused by the exceptionally high rise in the Chindwin, when the Irrawaddy proper was

only in moderate flood and a good deal below maximum flood levels previously recorded.

The Irrawaddy is subject to high floods from July to September. When the river level at Henzada is 42.5 ft., with a corresponding discharge of 37,700 c.m.s. (1,330,000 c.f.s.), it is considered to be dangerously high.

The duration of floods above danger level is approximately 28 days. The flood level is then more or less constant with a rise or fall of approximately 7.5 to 10 cm. (3 to 4 in.) for each successive wave of flood. The cultivators have the most anxious time, when the high rises in the river in July to August synchronise with heavy rainfall and high tides. Their fields are usually 3 to 4.5 m. (10 to 15 ft.) lower than the river levels. The plight of the villagers and agriculturists cannot be regarded as anything but very precarious. An example of the failure of Nga-Wun Embankment, in 1923 can be cited. During a breach in this embankment, the area submerged was 132,000 ha. (324,313 ac.), of which 84,000 ha. (206,635 ac.) had to be replanted. Besides loss of property and cattle, the cost of replanting a second crop is 2.5 times more expensive. In addition to heavy cost of replanting, the cultivators also suffer from reduced yield of crops. In most cases, replanted crops are only partially successful. The duration of floods is a most important factor in the destruction of crops. Young plants cannot stand immersion for long periods. Crops planted early in the season become hardy and can stand immersion for a period not exceeding 10 days in clear water.

No records are maintained of annual damage as a result of floods. The figures below give the damage resulting during 1947 — a year of very high floods.

Planted areas submerged	235,000 ha. (578,581 ac.)
Planted areas submerged but not destroyed	95,000 ha. (232,109 ac.)
Planted areas submerged but replanted	118,000 ha. (288,480 ac.)
Planted areas submerged and completely destroyed and not replanted	23,000 ha. (57,992 ac.)

Government expenditure to relieve distress due to floods totalled Rs. 1,400,000.

Records of the amount of indirect damage of floods are not available.

Flood Problem and Flood Control Activities

Irrawaddy Delta

From the point of view of land subject to inundation by floods from the Irrawaddy River, the delta can be divided into three sections.

- (1) Where upland floods have a paramount influence ;

- (2) Where the influence of upland flood water is felt and where, simultaneously, it is affected by the rise and fall of the tides ;

- (3) Where tidal movements are of primary importance and where upland floods have practically no effect on the water level.

In the first section, embankments have proved a conspicuous success. In the second section, embankments have not been completely satisfactory, because cultivation is frequently confined to a narrow fringe by the side of the embankment, and beyond it the land is low-lying, flooded and used for fish-breeding. In many cases these fisheries have deteriorated through being denied a periodical fresh water flushing. In the third section, embankments are not necessary. It is very important to note that the success of the embankments in the Irrawaddy Delta is largely due to proper maintenance care. The main flood problem then becomes the organizing of a labour force which will be on hand when danger threatens.

Every year white ants build nests inside the embankments, leaving no trace of their activities on the outside. Rats also find the dry earth of the embankments a good place to nest in. It is these white ant nests and rat holes which constitute the main weaknesses of embankments, and they are only revealed during high floods when leaks occur. To prevent a leak from becoming dangerous, it is necessary to detect its presence early and then to tackle it at once, before it reaches uncontrollable dimensions. During a flood, a leak is liable to occur anywhere in the length of an embankment. It is accordingly necessary to have a large labour force available for patrolling definite reaches. It would be most uneconomical to employ this large labour force throughout the rainy season. Fortunately the configuration of the river basin, combined with the climate characteristics of the region through which the river flows, permit prediction of flood levels at the head of the Delta. These predictions give information some eight days in advance of eventualities, which can accordingly be met with the required labour force.

Pyuntaza Plain

In addition to work along the Irrawaddy River, flood control is carried out by the Irrigation Department of Burma to a considerable extent in what is known as the Pyuntaza Plain, west of the Sittang River. The new method of "River Training without Embankments" here is worthy of special mention. The Pyuntaza Plain is that area of land which is bounded by the Sittang River on the east and the Pegu mountains on the west. Its area is approximately 3,600 sq. km. (1,400 sq. mi.) (see figure 16).. Rainfall run-off of the Pegu mountains and the plains in this area finds its way to the Sittang River, and so on to the sea through five main streams which flow in a general south-easterly direction. The five main streams

are called the Yenwe, Baingda, Kawliya, Kadok and Bawni. They have small catchment areas from 65 to 900 sq. km. (25 to 352 sq. mi.) and floods of short duration occur with discharges from 300 to 2,200 c.m.s. (10,000 to 77,000 c.f.s.). The silt discharge during flood season is rather heavy reaching 1 % by weight. The plain through which the rivers flow was at one time on the same general level as the banks of the river Sittang into which they empty. The banks of these streams were once so low that they were unable to contain their ordinary flood discharges, with the result that the entire plain became inundated every rainy season.

In about 1913 attempts were begun to exercise some control over the streams in the Pyuntaza Plain. The biggest of these is the Yenwe, and canals were excavated to the east and west of the railway line to connect up defined reaches of the existing channel. These attempts failed, because the canals silted up and the Yenwe changed its course. In the next phase an attempt was made to contain the stream between embankments raised on each bank, and to carry it within these embankments past the main lines of communication. This attempt continued from 1916 to 1925, but was finally abandoned because bed and flood levels had risen abnormally and the cost of raising and strengthening the embankments each year was increasing at a disproportionate rate.

River training without embankments started on the Yenwe stream in 1926, and during the first year's work flood levels at the railway bridge dropped from R. L. 50.2 ft. to 45.3 ft. Success was so patent that this method of flood control was applied to other streams in the Pyuntaza Plain.

The method consists of the practical use of bamboo stake side fences, parallel to the flow of water, with cross fencing to reinforce the parallel fence, wherever necessary.

As many as five rows of parallel fences are sometimes needed to control bank spill. The object of parallel side fences is to direct the flow of water along a selected line in the early stages of training, and to control overflow or bank spill in the later stages. A further purpose of these fences is to form gently sloping banks, by reducing the velocity of bank spill, thereby causing deposition of silt inside and outside the parallel fences. Cross fences are employed to control any water, which may tend to flow between parallel side fences.

The bamboo fences are made of bamboo stakes pointed and driven into the ground about 23 cm. (9 in.) apart with their tops dressed to an even height of about 60 to 75 cm. (2 ft. to 2.5 ft.) above ground level. These stakes are tied to horizontal bamboos about 15 cm. (6 in.) from their tops to hold them in position.

Where a depression is crossed, a stronger type of bamboo fence is required and in the case of a deep

depression, post weir fences are also used. When bank formation has been established, small openings are made in the bank's channel. These small openings are called silting sluices and the water flowing through them is heavily charged with silt. This silt is carried forward and deposited behind the bank already formed, thus making a wide bank, or is guided to depressions which are gradually reclaimed. The bed and side slopes of the silting gaps are protected with bamboo stakes.

The water which spills over the banks spreads over the land in thin sheets, depositing all its silt content in the process, and finally collects in drainage channels located in valleys between the main streams, which flow on ridges composed of their own silt. In this way the whole area acts as a retarding basin and permits considerable saving in the bridging required on the main lines of communication. Systematic reclamation of depressions on either side of the hill stream is carried out by means of silting gaps cut in its banks, with channels connecting these to the depressions, required to be reclaimed.

In many cases warping bunds are constructed at an acute angle to the main streams. These bunds collect and bring back much of the water which has spilled over the banks of the main streams, and which has deposited its silt. The water thus collected is comparatively clear and when it mixes with that in the main streams it helps the latter to carry forward its heavy silt charge by dilution.

Breaches in the silted banks are closed by fences, which induce silt to deposit in the breach site.

Flooding, i.e., spill of part of the river discharge over its banks, is an essential part of the method, but the flooding is controlled in such a manner as to be useful, instead of harmful. The streams are held to predetermined alignments so that the bridging provided carries away the flood waters which do not force new openings through main lines of communication.

The total cost of all works carried out in the Pyuntaza Plain amounts to Rs. 4,120,000. As a result of this expenditure 52,900 ha. (130,000 ac.) have been converted from marshland into highly cultivable land, which produces crops of the annual value of nearly Rs. 20 million. In addition to paddy, a fair amount of market gardening is carried out, and near many of the streams duck farms exist. Since drainage channels have been opened out, the public health of the area has been vastly improved.

The value of the work done can hardly be expressed in terms of money. There have been no breaches or interruptions to the main line of communication since 1937, and this has been such a boon to the country that the work is more in the nature of a public utility service.

KELANI GANGA

Summary of basic data

Total drainage area	2,300 sq. km.	890 sq. mi.
Area of upper basin (above Glencorse)	1,460 sq. km.	565 sq. mi.
Area of alluvial plain	840 sq. km.	325 sq. mi.
Length of river	103 km.	64 mi.
River slope on alluvial plain	1:4,000	
Average annual precipitation whole river basin	3,950 mm.	156 in.
Upper basin	5,060 mm.	199 in.
Lower plain	3,120 mm.	123 in.
Maximum flood discharge	4,150 c.m.s.	147,000 c.f.s.
Average annual discharge	148 c.m.s.	5,220 c.f.s.
Minimum discharge	30 c.m.s.	1,050 c.f.s.
Maximum flood volume	1,526,000,000 cu. m.	1,238,000 ac. ft.
Maximum annual run-off	3,800,000,000 cu. m.	7,146,200 ac. ft.
Average annual run-off	4,650,000,000 cu. m.	3,776,080 ac. ft.
Minimum annual run-off	3,960,000,000 cu. m.	3,204,000 ac. ft.
Average run-off per unit drainage area	.0644 c.m.s./sq.km.	5.88 c.f.s./sq.mi

General Features of the River Basin

The watershed of the Kelani Ganga (see figure 17) is situated east of Colombo, the capital of Ceylon, on the west coast. The shape of the catchment is comparable to a leaf with the stem in the sea at Colombo and the tip in the mountains. The major axis lies east and west and is about 103 km. (64 mi.) long, while the minor axis is 40 km. (24 mi.) wide. The river rises in the hills of the Central Province of Ceylon at an elevation of about 1,980 m. (6,500 ft.). The river takes a westerly course and reaches the sea north of Colombo after flowing a total distance of 103 km. (64 mi.). The total catchment area is 2,300 sq. km. (890 sq. mi.) which may be divided into two parts, a western section which is flat and an eastern part which is rugged and hilly. The last gorge traversed by the river is situated at Glencorse Estate, Avisawella, about 45 km. (28 mi.) from Colombo and the river bottom is at an elevation of 3.35 m. (11.4 ft.) above mean sea level. This gorge can be taken as the dividing line between the flat and the hilly portions of the catchment. The area above Avisawella (hilly catchment) is about 1,465 sq. km. (565 sq. mi.) and that below is about 840 sq. km. (325 sq. mi.).

From Avisawella, the river flows through the lower flood plain, which is marshy and has many sloughs and ponds. The lower plain is alluvial, except where the river cuts through ridges. At these points there are rocks which cause constriction of the flow. The river slope in the lower plain is approximately 1:4,000. The plain is highly developed and in many places the flood plain has been encroached upon. In addition, there are several bends in the river in this section between Avisawella and the sea.

Four separate levees totalling over 6 km. (4 miles) in length, located at some depressions, are provided along the left bank of the river near Colombo, for partial control of floods. Except for the railway embankment, which also serves for flood protection the other levees were built in 1923. These levees protect the area north and south of Colombo from a flood discharge up to 1,900 c.m.s. (67,000 c.f.s.), but large areas, urgently needed for city expansion, are unprotected. The levees on the right bank, which have a continuous length of 8 km. (5 mi.), and which have been in existence for seventy-five years, protect the areas on the right bank near Colombo. The top width of the levees varies from 1.8 to 6.1 m. (6 to 20 ft.) and the side slope from 1:1.5 to 1:2. Levees have no other bank protection except grass sods, which provide an effective cover against wave action.

The whole river basin is widely cultivated, the principal crops in the upper basin being tea and rubber and in the lower basin, coconut and rice. Above Colombo, there are few towns of consequence, most of the population living in small villages.

The North-East monsoon occurs between October and March and the South-West monsoon between April and September, causing rain storms to travel along the river basin. The average annual rainfall in the basin is 3,950 mm. (156 inches) and, due to orographic effects, the rainfall varies widely in the basin. Average annual rainfall is 3,120 mm. (123 inches) for the lower basin and 5,060 mm. (199 inches) for the upper basin. Generally a storm covers the entire basin. Precipitation producing destructive floods does not occur between any definite dates. The maximum record of 24 hours' precipitation at Ingoya Estate in

the upper basin on 15 July 1942 was 521 mm. (20.56 in.) Due to antecedent storms, the ratio of run-off to rainfall during major storms approaches unity.

The recorded minimum, average and maximum flow in the Kelani at Colombo are 30 c.m.s. (1,050 c.f.s.), 184 c.m.s. (6,500 c.f.s) and 3,960 c.m.s. (140,000 c.f.s.) respectively.

Floods and Flood Damage

Floods usually occur from May to September during the South-West monsoon, and from October to November during the North-East monsoon. The former gives the highest flood flow. The probable frequency of flood occurrence is as follows :

Discharge	Probable frequency of occurrence in 100 years
850 c.m.s. (30,000 c.f.s.)	85 times
1140 c.m.s. (40,000 c.f.s.)	50 times
1420 c.m.s. (50,000 c.f.s.)	25 times
1700 c.m.s. (60,000 c.f.s.)	16 times
1980 c.m.s. (70,000 c.f.s.)	12 times
2260 c.m.s. (80,000 c.f.s.)	9 times
2560 c.m.s. (90,000 c.f.s.)	8 times
2830 c.m.s. (100,000 c.f.s.)	5 times
4250 c.m.s. (150,000 c.f.s.)	2.5 times
5680 c.m.s. (200,000 c.f.s.)	0.9 times
8500 c.m.s. (300,000 c.f.s.)	0.1 times

Large floods occurring in recent years were those of 1930, with a peak discharge of 2,140 c.m.s. (75,000 c.f.s.) ; of 1940 with a peak discharge of 3,200 c.m.s. (112,600 c.f.s.), and of 1947 with a peak discharge of 4,150 c.m.s. (147,000 c.f.s.). The corresponding flood volumes were 1,060 ; 1,320 and 1,870 million cu. m., (383,630 ; 1,075,000 and 1,467,000 ac. ft.) respectively.

The natural channel capacity of the lower Kelani Ganga near Colombo is only about 710 c.m.s. (25,000 c.f.s.). The capacity of flood flow within embankments is approximately 1,900 c.m.s. (67,000 c.f.s.). Therefore, a higher flood flow will lead to overtopping of dikes with possible breaches. The damage due to minor floods such as in 1930 was due to the inadequate cross-section of embankments and the lack of maintenance. They inundate vast areas of land around Colombo in the lower plain.

Floods of the lower Kelani are caused by large amounts of precipitation, channel constrictions, lack of adequate free way at bridges, sand bars at the river mouth and the poor channel regime, which is heavily obstructed by sand from soil erosion, due to poor farming practices on the tea estates in the upper watershed.

A detailed flood damage survey was carried out after the flood of May 1940 for which the following figures are available :

Flood damage of Kelani Ganga in 1940.

Immovable property	Rs. 462,923
Movable property	223,632
Agricultural property	229,704
Crops in storage	1,037
Livestock	7,027
Damage to land	2,199
Land out of production	21,560
Clearing up	23,553
Business loss	69,546
Additional living expense	94,605
Depreciation : miscellaneous	701,725
Fighting floods	4,057
Public utility losses	137,884
Total	Rs. 1,979,452

The flooded area of the 1949 flood amounted to about 186 sq. km. (72 sq. mi.). About 5 per cent of the inundated land lay within the city of Colombo, while 41 per cent was in the suburbs and the remainder in the lower plain. Fifty nine thousand people were displaced as a result of this flood. Detailed figures for damage by the flood of 1947, which was greater than that of 1940 and affected 135,250 people, are not available, but it is known that between Rs. 2,500,000 and Rs. 3,000,000 were spent by the Government on flood relief and flood damage compensation. In a study made by a consulting engineer (1) on a proposed project for the Kelani Ganga, based on the 1940 flood damage data and field surveys, he estimated the annual average direct and indirect flood damage as Rs. 2,400,000.

Flood Control Measures and Proposed Plan

Up till now flood protection of Colombo and its suburbs has depended on existing small embankments. Many schemes have been drawn up to solve the flood problem. Of these three may be singled out for special mention.

(1) Flood channel and embankment.

As the discharge capacity of the present channel to the sea is inadequate and leads to flooding of the plain, the scheme proposed by the Flood Control Committee of the Government is to dredge a new channel, with embankments on both banks, to carry the flood flow to the sea. The design peak discharge is 6,200 c.m.s. (220,000 c.f.s.). The new channel would be 10.4 km. (6.5 mi.) long, 384 m. (1,200 ft.) wide and 6.05 m. (20 ft.) deep of which 3 m. (10 ft.) is to be above ground level and an equal amount below. The height of the embankments would be about 4.5 m. (15 ft.). The cost of this project, including two new

(1) J. S. Cotton : Control of the Kelani Ganga, 1948, p. 7.

bridges to span the flood way, two new sets of lock gates to keep out floods at the intersection of the existing river channel and the proposed floodway and various appurtenant works, was estimated by the Flood Control Committee at Rs. 162,000,000 in October 1949. According to the consultant's report (1) the annual cost of the project is Rs. 6,320,000 (based on a capital outlay of Rs. 105,100,000). When revised for capital cost of Rs. 162,000,000 the annual cost would be Rs. 9,096,000 and the average annual benefits including prevention of floods, change of land use etc., were estimated at Rs. 5,230,000.

(2) Series of dams in the upper reaches of the basin.

In this scheme, investigated by the Flood Control Committee, smaller dams were proposed at sites designated below, which could deal with a design flood of 7,090 c.m.s. (250,000 c.f.s.), of which 3,250 c.m.s. (115,000 c.f.s.) would be absorbed by the reservoirs.

Dam Site	Storage capacity	Hydro-power development
Mousakelle	73,000,000 cu.m. (59,000 ac.ft.)	45,000 kw.
Rondura	178,000,000 cu.m. (144,000 ac.ft.)	24,000 kw.
Yogaina	114,000,000 cu.m. (93,000 ac.ft.)	6,000 kw.
Imbulana	230,000,000 cu.m. (186,000 ac.ft.)	—

In addition to these dams, the scheme contemplated the improvement and canalization of the river channel from Hanwella to convey a maximum discharge of 3,850 c.m.s. (136,000 c.f.s.). This would require the strengthening, raising and realigning of the existing flood bunds and the excavation of a subsidiary channel to the sea. The approximate cost of this scheme is estimated at Rs. 301,196,000.

(3) Multi-purpose dam at Glencorse.

This scheme, prepared by a firm of engineering consultants (2), recommends the construction of a

multiple-purpose reservoir with an earth dam at elevation 61 m. (200 ft.) above mean sea level (river bottom elevation 3.5 m. or 11.4 ft.). The storage capacity of the reservoir would be 3,700 million cu.m. (3,000,000 ac.ft.) capable of reducing a design flood of 7,100 c.m.s. (250,000 c.f.s.) to 1,900 c.m.s. (67,600 c.f.s.) with a flood volume of 2,720 million cu.m. (2,200,000 ac. ft.). In addition, primary and secondary power output are estimated at 24,000 kw. and 36,000 kw., respectively. The river channel lower down would be improved and canalized to convey the reduced flood flow, so as to prevent flooding of the riparian interests, from the reservoir to the sea.

The capital cost of the scheme, as worked out by the consulting firm, with data available at that time, was Rs. 117,256,560 and the annual benefit was estimated at Rs. 8,630,000, while the annual charge would be Rs. 6,523,000. Thus the benefit cost ratio is 1.32. Investigations conducted by Government officials later ascertained that flowage damage (submergence of reservoir area) alone would reach Rs. 669,900,000, thus making the proposal economically unjustified.

The Kelani Flood Control Committee of the Ceylon Government, after careful examination of the above mentioned proposals, decided to recommend adoption of the flood channel and embankment scheme as a solution of the flood problem. In selecting a particular flood control method, the committee took into consideration the urgency of relief within a reasonable time to areas at present subject to flooding and also the financial resources of the country. Detailed investigation of the flood channel scheme is to be carried out while, before any actual construction is begun, the strengthening of the existing dikes will be undertaken.

(1) Ibid, p. 22.

(2) International Engineering Co. : Report on Flood Control.

KOSI RIVER

Summary of basic data

Total drainage area	61,600 sq. km.	23,808 sq. mi.
Sun Kosi	19,200 sq. km.	7,424 sq. mi.
Arun	36,500 sq. km.	14,106 sq. mi.
Timur	5,900 sq. km.	2,278 sq. mi.
Area under glacier	5,760 sq. km.	2,228 sq. mi.
Slope of river during high water on alluvial plain		
Chatra — Raniganj (42 km., 26 mi)		1:1,050
Raniganj — Bhaptiahi (32 km., 20 mi)		1:2,010
Bhaptiahi — Supaul (40 km., 25 mi.)		1:4,530
Supaul — Dhamara Ghat (97 km., 60 mi)		1:7,300
Dhamara Ghat — Naugachia (35 km., 53 mi) ..		1:23,000
Naugachia — Kursela (22 km., 14 mi.)		1:17,800
Average annual precipitation	1,790 mm.	70.4 in.
Maximum flood discharge (design)	27,100 c.m.s.	956,000 c.f.s.
Average annual discharge (1948)	1,930 c.m.s.	68,200 c.f.s.
Average annual run-off (1948)	60,700,000,000 cu. m.	49,240,198 ac. ft.
Average annual silt run-off (1948) Chatra	116,000,000 cu. m.	94,418 ac. ft.
Average annual run-off per unit area	c.m.s./sq.km.	2.86 c.f.s./sq.mi

General Features of River Basin

The Kosi River, a tributary of the Ganges, is the third largest of the Himalayan rivers, being next in size to the Indus and the Brahmaputra. Its drainage area covers 61,600 sq. km. (23,808 sq. mi.) of which 5,760 sq. km. (2,228 sq. mi.), are under glaciers. The Kosi basin contains the highest peaks in the world, Mount Everest and Kinchinjunga, and the largest glaciers known in Nepal lie within its drainage area.

The Kosi (see figure 18) is a perennial stream formed by the confluence of three tributaries, the Sun Kosi from the west (drainage area 19,200 sq. km. or 7,424 sq. mi.), the Arun from the north (drainage area 36,500 sq. km. or 14,106 sq. mi.), and the Timur from the east (drainage area 5,900 sq. km. or 2,278 sq. mi.). The Arun is the largest branch of the Kosi, which extends into Tibet. The watershed above the confluence of the three tributaries has a fan-shaped drainage area, composed of steep mountain ranges. The steep hills are fully covered by forests, but rapid deforestation is taking place in the catchment of the Sun Kosi and some of its tributaries. Unrestricted cattle grazing in these areas has caused denudation of vegetation and accounts for the heavy silt run-off of the river.

Below the confluence, the Kosi flows for about 9 km. (6 mi.) in a narrow gorge to its debouch into the plains near Chatra. Further downstream the river, following a general north-south direction, runs in an alluvial plain and finds its way southwards into the Ganges through a number of channels. In each of these the bed is gradually raised by huge masses of boulders, pebbles, sand and silt it brings down. When the river is swollen by heavy rain it cuts through the friable soil and seeks a new channel. An alluvial cone is formed in the low-lying country, with the apex of the cone located at the point of the river's debouch from the hills at Chatra, and its sides passing near Purnea on the east and Darbhanga on the west to a distance of 153 km. (95 mi.). The ridge of this cone runs along a line almost due south from the mouth of the Chatra gorge to the Ganges in the neighbourhood of Naugachia. Boulders of 10 to 12 cm., (4 to 5 ins) in size are found in the river bed near Chatra to a depth of several feet, intermingled with coarse sand. Further downstream the bed consist of a variety of sand and beyond this it is composed of a mixture of fine sand and clay which continues up to its outfall.

On the alluvial cone the country slopes from north to south. The slope of the river on the plain from Chatra down to the confluence with the Ganges varies from 1:1,050 to 1:23,000 during high water period.

Though a very old river, the Kosi has not yet carved out a permanent and definite course for itself. It is still in an unstable stage and has been constantly changing its course. During the last 200 years it has been moving in a westerly direction over a total dis-

tance of 112 km. (70 mi.), because the river has been flowing on that part of the alluvial cone which has a transverse slope from east to west. The following table shows the approximate rate of movement of the Kosi between 1736 and 1933 measured on a line passing through Belhi and Purnea.

Shifting of the Kosi River from 1736 to 1933.

Year	Period in years	Distance moved		Rate of movement	
		km.	mi.	km./year	mi./year
1736-1770	34	10.8	6.7	0.32	0.2
1770-1823	53	9.3	5.8	0.16	0.1
1823-1856	33	6.1	3.8	0.18	0.1
1856-1883	27	12.9	8.0	0.48	0.3
1883-1907	24	18.5	11.5	0.77	0.5
1907-1922	15	11.0	6.8	0.73	0.45
1922-1933	11	29.0	18.0	2.63	1.60

In these movements it has laid waste large areas of agricultural land estimated between 5,200 and 7,800 sq. km. (2,000 and 3,000 sq. mi.). During floods the Kosi carries immense volumes of silt. Large areas in Bihar and Nepal remain submerged for prolonged periods, resulting in the destruction of crops, blocked communications, stagnating pools and malaria. Large masses of sand are deposited by the river over rich fields, making them unproductive for many years. The Kosi flood plain is densely populated with about 900 persons to the square mile.

The normal annual precipitation in the catchment is 1,790 mm. (70.4 in.) with the most intensive rainfall from July to September. The annual run-off, based on measurements carried out in 1948, was 60,700 million cu.m. (49.24 million ac.ft.). No data is available for the duration and frequency of flood flow. It is estimated that the maximum discharge may be between 19,000 c.m.s. to 28,300 c.m.s. (700,000 c.f.s. to 1,000,000 c.f.s.).

The results of silt investigations carried out during 1947 and 1948 disclosed an abnormally high rate of silt yield per unit catchment area, higher than any other river in the world including the Yellow River of China. The annual silt discharge of 1948 reached 116,000,000 cu. m. (94,418 ac. ft.) and the unit yield was 1,960 cu. m. per sq. km. (410 ac. ft. per 100 sq. mi.). The monthly mean silt concentration varies from 0.07 per cent to 3.05 per cent by volume. Unlike other rivers of India, which carry large quantities of fine silt, the Kosi carries down a considerable amount of medium size silt.

Floods and Flood Damage

The Kosi is subject to sudden spates sometimes rising over 9 m. (30 ft.) in 24 hours. When swollen by the melting of snow, or by annual rains, the river overflows its banks and spreads over a vast tract. From Chatra down to the Indian border the flood spill of the Kosi extends from 1.6 to 5 km. (1 to 3 mi.) east of the river, with the depth varying from 0.6 to 1 m. (2 to 3 ft.), while to the west the floods remain

confined within the right bank. From the border down to Bhaptiahi, a distance of about 45 km. (28 mi.), the spill on the east of the river spreads from 1.6 to 5 km. (1 to 3 mi.) to a depth of from 0.3 to 1 m. (1 to 3 ft.) and on the west it extends over a large area from about 8 to 16 km. (5 to 10 mi.) wide with depths varying from 0.6 to 2 m. (2 to 6 ft.). Beyond Bhaptiahi up to the railway line, a distance of 70 km. (45 mi.), major portion of flood spill concentrates in the west and spreads over a wide area to a width of approximately 20 km. (12 mi.) and an average depth of 1.5 m. (5 ft.) with practically no spill on the east. The spilling on the west has been increasing year after year, and during 1938 it was observed to be 50 per cent of the flood discharge. At the exit through the railway line the width of spill is about 13 km. (8 mi.) with a depth varying from 2 to 3 m. (6 to 10 ft.). Emerging from the openings in the railway line the flood spill flows eastwards taking the course of the Ghugri channel which also spills over both banks. The extent of spilling in this area fluctuates according to the level of the Ganges River.

The flood of July 1948 caused considerable damage. The flooded area covered 1,300 sq. km. (500 sq. mi.) which is almost equivalent to the area covered by the 1938 flood, the highest on record. The unexpected early rise of the flood waters caused great damage to standing maize and moong crops, from 70 to 80 per cent of which were destroyed. Standing paddy crops also suffered heavy damage. Breaches of the railway line and highways disrupted normal communications.

The Kosi flood plain suffers (in common with areas in Bengal and Orissa) not only from too much, but also from too little water. At times it is subjected to floods and at others to droughts, owing to the failure of rain. Many districts in the plain have frequently suffered from famine. In the famine of 1769-1770, one-third of the population of Bengal (which then included Bihar) is said to have perished. The great famine of 1865, which took such a heavy

toll of life in Orissa, caused acute distress in the Kosi area.

The Kosi flood plain thus suffers from uncontrolled devastating floods, from masses of sand carried by the flood waters which, when deposited on fertile land makes it unproductive for long periods, from continuous oscillation of the Kosi bed which destroys towns, villages and cultivated lands, from blocked waterways and stagnant pools and from virulent malaria. Although considerable areas occasionally benefit from fertilizing silt carried by the floods, the damage and devastation caused by the latter far exceed those benefits.

Flood Problem and Proposed Plan of Flood Control

Since 1937 the problem of the Kosi has been engaging the attention of the Government of Bihar. Whether embankments should, or should not, be built has long been discussed. In the Bihar post-war development plan a proposal was put forward to confine the river in a definite channel by the construction of parallel embankments about 16 km. (10 mi.) apart at an approximate cost of 100 million rupees.

In 1946 the Central Waterpower Irrigation and Navigation Commission, after survey and investigation, drew up a multiple-purpose scheme to provide flood control, silt control, soil conservation, irrigation, drainage, reclamation of waterlogged areas, malaria control, navigation, hydro-electric power development, fish culture and recreational facilities.

The multiple-purpose scheme proposed the construction of a high dam across the Chatra Gorge in Nepal on the assumption that, during a maximum design flood of 27,100 c.m.s. (956,000 c.f.s.), a regulated flow of 6,900 c.m.s. (250,000 c.f.s.) will pass down the river without doing any material damage to the plain. Among the many alternative proposals now being investigated, the salient features of the most economical one are as follows:

Salient features of the Kosi Dam Project.

Height of dam above foundation	239 m.	783 ft.
Height of reservoir --- full level above foundation	232 m.	760 ft.
Height of spillway crest above foundation	219 m.	720 ft.
Length of spillway	290 m.	952 ft.
Length of dam	605 m.	1,985 ft.
Capacity of Reservoir		
Total	8,550,000,000 cu. m.	6,910,000 ac. ft.
Flood control	3,710,000,000 cu. m.	3,000,000 ac. ft.
Dead storage	3,710,000,000 cu. m.	3,000,000 ac. ft.
Reserve	1,130,000,000 cu. m.	910,000 ac. ft.
Firm power at 60 % load factor (ultimate)		1,600,000 kw.
Irrigation	500,000 to 1,200,000 ha.	2,000,000 to 3,000,000
Concrete volume of dam ⁽¹⁾	7,160,000 cu. m.	9,410,000 cu. yd.
Excavation volume of dam ⁽¹⁾	5,270,000 cu. m.	6,910,000 cu. yd.
Approximate cost of dam (excluding power plant)		544 million Rs.
Approximate cost of irrigation scheme		300 million Rs.

(1) Compare with the big two dams of U.S. (in million cu. m.)

	Concrete	Excavation
Boulder Dam	3.36	2.67
Grand Coulee	8.6	17.57

The proposed concrete dam is a straight gravity type with power house in the dam, three drum gates of 41 m. $\times$ 12 m. (135 ft. $\times$ 40 ft.) in the overflow sections, and one of the same size in front of each of the four diversion tunnels used for spillways. Regarding dead storage for silt, it is assumed that 90 per cent of the medium and coarse silts and 15 per cent of the fine silt will deposit in the reservoirs, giving an annual total of 63 million cu. m. (50,900 ac. ft.). The proposed dead reservoir volume of 3,710 million cu. m. (3 million ac. ft.) should be sufficient for about 60 years and the reserve capacity of 1,130 million cu. m. (910,000 ac. ft.) would add 20 years of life to the silt storage. Check dams are proposed to be constructed and other soil conservation measures are recommended in the Nepal hills to remedy the silting problem.

A barrage is proposed to be constructed downstream of the dam, to stabilize the Kosi in one or more defined channels, and to divert the river flow to both banks for the development of irrigation. The gross area commanded on the east bank (Nepal and Bihar) is 1.34 million ha. (3.33 million ac.) and the

net irrigable area is 830 thousand ha. (2.04 million ac.). Approximately 400 thousand ha. (1 million ac.) on the west bank is also readily available for irrigation. Utilizing the head available in canals, 100,000 kw. of hydro-electric power can also be developed. The cost of this irrigation scheme, including power plant in canals, is estimated at Rs. 300 million.

As the construction of the Chatra dam will take from 11 to 20 years, it is proposed to carry out as a first stage, covering four years, the construction of the barrage and the irrigation works including water power scheme. That would enable the development of the Chatra dam project to be accelerated by providing the necessary power, rail and bridges, etc., for the construction work. Besides, a fair measure of temporary flood protection would be provided by the network of irrigation canals, with the banks serving as flood control embankments, thus localizing the spread of flood flow.

The detailed plans of the project are now being prepared by the Central Waterpower Irrigation and Navigation Commission of India.

MAHANADI RIVER

Summary of basic data

Total drainage area	132,000 sq. km.	51,000 sq. mi.
Area of river delta	20,000 sq. km.	8,000 sq. mi.
Length of river	856 km.	533 mi.
River slope		
Hirakud to Tikarapara	1:2,080	
Tikarapara to Naraj	1:3,520	
Naraj to sea	1:4,900	
Average annual precipitation ..	1,380 mm.	54.38 in.
Maximum annual precipitation ..	1,810 mm.	71.21 in.
Minimum annual precipitation ..	940 mm.	37.02 in.
Maximum flood (design) at Naraj	48,100 c.m.s.	1,700,000 c.f.s.
Average annual discharge at Naraj	2,850 c.m.s.	101,000 c.f.s.
Minimum annual discharge at Naraj	43 c.m.s.	1,500 c.f.s.
Maximum flood volume (design) at Hirakud	5,540,000,000 cu. m.	4,490,000 ac. ft.
Maximum annual run-off at Naraj	127,800,000,000 cu. m.	103,670,000 ac. ft.
Average annual run-off at Naraj	91,500,000,000 cu. m.	74,050,000 ac. ft.
Minimum annual run-off at Naraj	37,400,000,000 cu. m.	30,370,000 ac. ft.
Average annual run-off per unit area	.0216 c.m.s./sq.km.	1.98 c.f.s./sq. mi
Annual silt run-off (1947)	41,000,000 cu. m. (61,500,000 tons)	33,235 ac. ft.

General Features of the River Basin

The Mahanadi River basin (see figure 19), situated on the east coast of India below Calcutta, has a drainage area of 132,000 sq. km. (51,000 sq. mi.) and

extends approximately from longitude 80°30'E to 84°50'E and from latitude 19°20'N to 23°35'N. The river basin can be divided into three parts, the upland plateau, the central hilly portion crossed by the eastern Ghats, and the delta area.

The upland plateau with an elevation of 150 to 230 m. (480 to 750 ft.) is a wide expanse of fairly open country fringed by forested hills and intersected by the Mahanadi River. Broadly speaking, it is an undulating upland tract broken by rugged ranges of hills, and is criss-crossed in all directions by drainage channels leading from the hill ranges to the Mahanadi.

The portion separating the upland plateau from the delta comprises a chain of hills with thickly wooded slopes and fertile valleys lying between them. The greatest distance of this hilly region from the sea coast is about 96 to 112 km. (60 to 70 mi.), but in many places it does not exceed 24 to 32 km. (15 to 20 mi.). The hills do not exist as long continuous ranges, but are generally irregularly scattered in groups and for the most part are covered with vegetation.

The delta area is nearly 20,000 sq. km. (8,000 sq. mi.), out of which the central portion of 7,800 sq. km. (3,000 sq. mi.) is particularly subject to flooding. It is, however, the most fertile and densely populated tract in Orissa.

The Mahanadi River, with a total length of 856 km. (533 mi.), rises near Sihawa in the south-western part of the river basin. In the first part of its course it flows to the north. For the first 30 km. (50 mi.), its valley is not more than 450 to 550 m. (1,500 to 1,800 ft.) wide. The Mahanadi, after receiving the waters of its first great tributary, the Seonath, flows eastward and is joined by its principal tributaries, the Hasdo and the Mand. The river then turns south and flows south and south-east, finally becoming a major river with a width of over 1.6 km. (1 mi.). Here its tributaries are the Ib, and Tol in addition to numerous minor streams. Subsequently it forms a series of rapids until it reaches the outermost line of the eastern Ghats. The mountain line is pierced by a gorge 64 km. (40 mi.) in length, and the Mahanadi finally emerges from a valley 1.6 km. (1 mi.) wide and enters the Orissa delta about 11 km. (7 mi.) west of Cuttack. It traverses Cuttack district from west to east throwing off numerous branches, and falls into the Bay of Bengal through several channels near False Point.

On the right or south bank, above Cuttack, the Mahanadi gives off a large stream, the Katjuri. The city of Cuttack is built in the fork of the two channels.

The Katjuri immediately divides into two, the southern branch under the name of Kuakhai, running for a short distance before throwing off the Surna which unites with the parent stream after a course of a few miles. The off-shoots from the left, or north bank of the Mahanadi, are the Borupa and Chitratala. The former takes off opposite Cuttack and later joins the Brahmani, a river north of the Mahanadi basin.

The river delta of the Mahanadi comprises an area of 20,000 sq. km. (8,000 sq. mi.) which is criss-crossed by the main river and its branches. Diking

of the delta began in the 19th century and was later taken over by the Government. At the beginning of the 20th century, a study of the existing dikes was undertaken. Some were abandoned, others were repaired and maintained by the Government (figure 19). As the total discharging capacity between the banks of the branches of the river in the delta is not able to hold the maximum flow, it has been found necessary to pass down the flood, in excess of a certain elevation, over high level masonry escapes in the marginal embankments, at selected spots, otherwise the height of flood embankments to be maintained would be excessive. In certain areas like the mid-Baitarani and the Subanarekha, further embanking is not considered desirable. There are two classes of flood embankments — the capital and the ordinary agricultural class. The first protects irrigation schemes and important towns, and the latter covers the rest. Both classes of embankments are designed with a crest level of 0.9 m. (3 ft.) above the maximum flood level. The crest width is 1.5 m. (5 ft.) for the ordinary type and 3 m. (10 ft.) for the capital and also the ordinary type, when the latter is constructed with sandy soils. Side slope on the river side is 1:2 and on the land side 1:3. For dikes higher than 3 m. (10 ft.), a berm is added on the land side; below the berm a slope of 1:4 or 5 is adopted. Where erosion of the slope is caused by wave wash the slopes are planted with a type of tall grass which grows from 1.2 to 2.7 m. (4 to 9 ft.) high depending on the soil, and affords protection against wave action. Where the planting of long grass is not desirable, or where the river is scouring close to the embankment, stone revetment 30 cm. (1 ft.) thick is constructed. In cases of emergency, bamboo basket work with bamboo piles is provided, and sand bags and bamboo mats are also employed. The stone pitching, or revetment, is generally laid on a 1:1.5 slope and sometimes 1:2 slope, and a 1.5 to 2.5 m. (5 to 8 ft.) horizontal apron 60 cm. (2 ft.) thick provided at the toe where scour is anticipated. Protection by means of spurs against scour is done to a very limited extent. Where the attack is considered temporary, permeable pile and brushwood spurs are found effective, if the scour is not too deep. Permanent stone spurs are provided occasionally in small sections where trouble is deep-seated. Flood embankments in the delta, where considered necessary, are definitely economical. The saving in food crops in 4 to 5 years equals the cost of the embankment.

The mean annual rainfall over the river basin varies from 940 mm. (37.02 in.) to 1,810 mm. (71.21 in.) with an annual mean of 1,320 mm. (54.33 in.). Except in the delta, over 85 per cent of the annual rainfall occurs in the monsoon period from June to September. Floods are due to the heavy precipitation of the storms which develop in the Bay of Bengal. The general track of the centre of storms is in a west-north-west direction and crosses the northern part of

the river basin at an average rate of travel of 320 km. (200 mi.) per day. The isohyetal lines from June to September show that the heaviest rainfall of 1,500 mm. (60 in.) is confined to a small area between Sambalpur and Sonepur. The next heaviest rainfall is in the north-east part of the catchment. The central and southern parts of the catchment receive about 1,140 mm. to 1,270 mm. (45 in. to 50 in.) of rain, while the eastern portion receives much less. Precipitation over the catchment north of the delta is much higher than in the delta itself.

The Mahanadi is not a snow-fed river and floods occur during the period of heavy rainfall from June to September. Extraordinary precipitation occurs every five or six years in the upper basin of the catchment, and causes heavy floods which submerge crops long enough to damage or destroy them. The floods also bring sand and silt, which they deposit lower down, blocking up the river course and damaging fertile land.

The frequency of flood occurrence at Sambalpur and Naraj is given below :

Frequency of flood once in	Discharge at Naraj		Discharge at Sambalpur	
	c. m. s.	c. f. s.	c. m. s.	c. f. s.
10,000 years	48,100	1,700,000	34,100	1,205,000
1,000 —	46,700	1,650,000	33,100	1,170,000
500 —	46,400	1,640,000	32,800	1,160,000
250 —	46,100	1,630,000	32,600	1,150,000
100 —	44,500	1,570,000	31,400	1,110,000
50 —	43,000	1,520,000	30,400	1,075,000

The safe flood discharge at Naraj, at the head of the delta, is accepted as 34,400 c.m.s. or 1,215,000 c.f.s., which corresponds to a gauge height of 90.1 feet.

Measurement on silt flow carried out in 1947 at Sambalpur gave the annual silt run-off at 41 million cu. m. (33,235 million ac. ft.), or roughly 0.065 per cent of the annual water run-off by volume. Over 75 per cent of the silt load is composed of fine silt having a diameter smaller than 0.075 mm.

Regarding soil erosion on the headwaters, the Mahanadi basin can broadly be divided into State forests, private forests and agricultural fields. The first named are well looked after and soil erosion is negligible. Soil erosion is considerable on private forests. The agricultural fields are well cared for, but immediately above the rice fields there exist sloping dry lands which suffer a loss of soil annually during the rainy season. No systematic soil conservation measures have been undertaken so far in this catchment to enable the determination of their effect on flood run-off and silt discharge. The Central Water-power, Irrigation and Navigation Commission, who have taken in hand the construction of the Hirakud Project, contemplate a detailed plan of soil conservation measures. There are, however, appreciable tracts of forests in the catchment, which do help in moderating the effect of high floods.

Floods and Flood Damage

Several heavy floods occurred in the Mahanadi basin in 1855, 1872, 1911, 1919, 1920, 1925, 1927, 1929, 1933 and 1937, but no detailed information about them is available.

In the delta, except for a few small localities, flooding of any importance is only the result of floods originating in the upper reach of the river and not of local rainfall. Only very occasionally, when precipitation attains a magnitude of about 250 mm. (10 in.) in 24 hours, does serious local flooding occur near the hills. Inundation of the country in the delta occurs through overflow of the river banks and submergence of unprotected areas. Damage sometimes follows when flood embankments are breached. Some damage is also caused by the discharge through high flood escapes in the embankments.

A round evaluation of the flood damage in 1933 and 1937 is given below. The figures for other years are estimated on the basis of those of 1933 and 1937.

Flood damage of Mahanadi delta

1911	Rs.	5,000,000
1919	Rs.	6,600,000
1920	Rs.	2,900,000
1925	Rs.	2,300,000
1926	Rs.	6,000,000
1927	Rs.	3,500,000
1929	Rs.	2,000,000
	Rs.	26,300,000
1933 — House damage	Rs.	105,000
Crop damage	Rs.	5,395,000
Public Works	Rs.	56,000
Roads etc.	Rs.	37,000
	Rs.	5,593,000
1937 — House damage	Rs.	29,000
Crop damage	Rs.	2,862,000
Public Works	Rs.	59,000
Roads etc.	Rs.	13,000
	Rs.	2,963,000
Total	Rs.	34,856,000

Therefore, for a period of 29 years from 1910 to 1938, total direct damage from floods was estimated at Rs. 34,865,000 with average annual losses estimated at Rs. 1,200,000. The damage to public works includes repairs to canals, levees and emergency expenditure. Siltation of irrigation canals is not excessive, as all are protected by marginal embankments. Canals at their heads are closed to exclude the excessive silt charge during floods.

Indirect damage is also believed to be considerable. Public utilities are not numerous, and are not so heavily affected as industries. Loss of human life is practically nil and loss of livestock very small.

Flood Problem and Proposed Plan of Flood Control

For effective flood control in the Mahanadi Basin, there are two schemes in hand. The first concerns

flood protection embankments being constructed by the Orissa Government and the second the unified development scheme under the Central Waterpower, Irrigation and Navigation Commission.

Flood Protection Embankments.

The Orissa Government has adopted the policy recommended by the Orissa Flood Advisory Committee ⁽¹⁾ which includes :

- (1) Conservation and improvement of main rivers by a system of adequate embankments and by the provision and maintenance of efficient outlets to the sea, to enable the rivers to carry their normal flood discharge for which the slope is ample.
- (2) Prevention of breaches in embankments which lead to deterioration of the main river.
- (3) Provision of high level escapes, so designed as to pass only the finer grades of silt and spill water, in excess of a predetermined figure, over adjacent land.
- (4) Control of deforestation in the catchment areas.

In executing this policy it may be necessary, in certain cases, to carry out river training works such as closing certain channels, developing others, constructing spurs to control the direction of flow and protecting river banks.

The adoption of this policy has now been qualified by the possibilities of unified development of the Mahanadi. The multiple-purpose reservoirs will detain the flood flow. Reservoirs are also proposed at a future date on the Brahmini and Baitarani rivers. They will be capable of reducing the intensity and duration of high floods, and the height of embankments can then be reduced, even if the embank-

ments are not entirely abandoned. The regime of the rivers will be altered by the reduction in peak discharges and by the more regular flow. With the reduction in flood discharge, it would be possible to close the flood escapes in the embankments and several of the river branches in the delta, and confine the flow to one or more main rivers, according to the above policy.

Multiple-purpose development scheme.

The unified development scheme ⁽¹⁾ of the Mahanadi Valley comprises three multiple-purpose reservoirs, the Hirakud Dam Project (upstream above Sambalpur), the Tikarapara Dam Project and the Naraj Dam Project (at the head of the delta). The Hirakud and the Tikarapara Projects are capable of independent development without prejudicing, or being prejudiced, by any other part of the unified scheme, and are further capable of forming an integral part of the combined development. Some of the salient features of the three projects are shown in the attached table and a brief description is given below :

The Hirakud Dam Project contemplates the construction of a dam across the Mahanadi about 15 km. (9 mi.) above the town of Sambalpur. The dam would be 4,700 m. (15,700 ft.) long of which 1,500 m. (5,000 ft.) will be a concrete gravity overflow dam, and the balance earth and rock fill, with gravity and lift canals on either side for irrigation and two hydro-electric installations. Regarding the flood control aspect of this project, the peaks will be reduced by the reservoir. The maximum flow in the river delta is obtained by adding the surface inflow, between Hirakud and the head of the delta, to the regulated flow from Hirakud Dam.

Maximum flood discharge in the river delta

FLOOD FREQUENCY	PEAK DISCHARGE RUNNING INTO HIRAKUD		REGULATED FLOOD DISCHARGE AT HIRAKUD		INFLOW BETWEEN HIRAKUD AND NARAJ		TOTAL DISCHARGE AT HEAD OF DELTA	
	C. M. S.	C. F. S.	C. M. S.	C. F. S.	C. M. S.	C. F. S.	C. M. S.	C. F. S.
10,000 years	34,100	1,205,000	23,500	830,000	14,000	495,000	37,500	1,325,000
1,000 —	33,100	1,170,000	21,800	770,000	13,600	480,000	35,400	1,250,000
100 —	31,400	1,110,000	21,000	740,000	13,000	460,000	34,000	1,200,000

The safe flood discharge at the head of the delta is accepted as 34,400 c.m.s. (1,215,000 c.f.s.) with a corresponding gauge height of 90.1 ft., an excess above which will result in damage to land and property

in the river delta. According to this accepted limit the project can definitely secure perfect flood control

(1) Orissa Flood Advisory Committee. *Third Interim Report of the Orissa Flood Advisory Committee*. Feb. 1942, p. 6.

(1) Central Waterways, Irrigation and Navigation Commission. *Mahanadi Valley Development, Hirakud Dam Project* June 1947, (Simla, Government of India Press) p. 15 and *CWINC Report of the Advisory Committee on the Hirakud Dam Project* 1948, (Simla, Government of India Press) p. 32.

for 100-year floods. Some damage will result from 1,000-year floods, but this will not be very material. For a 10,000 year flood, substantial damage will occur, but it will have to be faced only once in 10,000 years. Concerning the dead storage for silt, it is assumed that with sluices and siphons situated at the bottom of the reservoir, designed to discharge floods up to 22,600 c.m.s. (800,000 c.f.s.), a very substantial quantity of silt will be carried to the river channel below the dam. Assuming roughly that 1/3

of the annual silt load or 14,800,000 cu. m. (12,000 ac. ft) will be deposited in the reservoir, the life of the dead storage reserved for silt will be 100 years. When the silt reserve fills up, it is hoped that the deep sluices and siphons will increase the silt-discharge capacity many times, so that the rate of silting thereafter, will rapidly decrease and ultimately become too small to be of any consequence. Check dams to be constructed on the headwaters will also improve the conditions.

The total cost of the project is estimated as follows :

Dam and appurtenance work	Rs. 161,600,000
Main canal, branches, distributaries	78,000,000
Hydro-electric installations	228,500,000
Navigation	10,000,000
Total	Rs. 478,100,000

The allocation of cost to different purposes will be :

Flood Control	61,100,000
Irrigation	111,200,000
Power	295,800,000
Navigation	10,000,000

Total **Rs. 478,100,000**

The annual cost and benefit is as follows :

	Annual benefit Rs	Annual cost Rs	Net annual benefit Rs
Flood control	1,200,000 (not included)		
Irrigation	6,671,170	3,432,170	3,239,000
Power	25,200,000	7,981,250	17,218,750
3 % interest on capital		14,343,000	- 14,343,000
Total	Rs. 31,871,170	25,756,420	6,114,750

The benefit-cost ratio is thus 1.24. The project is now under execution by the Central Waterpower Irrigation and Navigation Commission. Drilling and exploratory work is nearing completion.

(2) Tikarapara Dam Project.

The Tikarapara gorge affords a dam site which is unique in the world. With a dam 100 m. (330 ft.) above low water level, it would be possible to store 135,350 million cu. m. (109.68 million ac. ft.), which is 50 per cent more than the total mean annual run-off of the Mahanadi River. With the entire run-off stored, there will obviously be no further flood

problem. The possible power output is 2.5 million k.w., and irrigation of 450,000 ha. (1,100,000 ac.) is possible. However, the area submerged by the reservoir at such a high level would be 475,000 ha. (1,168,000 ac.), which presents a problem. Investigation of the site for different reservoir levels is yet in a preliminary stage.

(3) Naraj Dam Project.

Situated at the head of the delta, the dam will be a complement of the Hirakud and Tikarapara projects. It would not be an economical proposition as an independent project for flood control or power. Investigation is in the preliminary stages.

Salient features of the Mahanadi Development Scheme.

NARAJ

TIKARAPARA

HIRAKUD

Discharge

Max. design flood	34,100 c.m.s.	1,205,000 c.f.s.	40,800 c.m.s. (a)	1,440,000 c.f.s. (a)	48,100 c.m.s. (a)	1,700,000 c.f.s. (a)
Min. discharge	26 c.m.s.	900 c.f.s.	38 c.m.s.	1,350 c.f.s.	43 c.m.s.	1,500 c.f.s.
Regulated max. discharge	23,500 c.m.s.	830,000 c.f.s.				
Regulated min. discharge	250 c.m.s.	8,900 c.f.s.	816 c.m.s. to 2,830 c.m.s.	28,800 c.f.s. to 100,000 c.f.s.	363 c.m.s. to 2,830 c.m.s.	12,800 c.f.s. to 100,000 c.f.s.
Height of dam above deepest bed	41 m.	132 ft.	63 m. to 109 m.	209 ft. to 359 ft.	33 m.	109 ft.

Storage capacity

Dead storage	1,480 mil.cu.m.	1.2 m.ac. ft.	7,100 mil.cu.m. to 16,900 mil.cu.m.	5.76 m.ac. ft. to 13.76 m.ac. ft.	3,620 mil.cu.m.	2.93 m.ac. ft.
Live storage	5,060 mil.cu.m.	4.1 m.ac. ft.	9,900 mil.cu.m. to 118,000 mil.cu.m.	8.00 m.ac. ft. to 95.92 m.ac. ft.	4,820 mil.cu.m.	3.90 m.ac. ft.
Total storage	6,520 mil.cu.m.	53 m.ac. ft.	17,000 mil.cu.m. to 135,000 mil.cu.m.	13.76 m.ac. ft. to 109.68 m.ac. ft.	8,430 mil.cu.m.	6.83 m.ac. ft.
Irrigation	442,000 ha.	1,094,953 ac.	445,000 ha.	1,100,000 ac.	445,000 ha.	1,100,000 ac.
Peak hydro-power at 60% load factory		300,000 kw.	432,000	to 2,500,000 kw.	107,000 kw.	to 510,000 kw.

Navigation : — Navigation by river craft carrying 800 tons from Bhelpur to the sea in distance of 550 km., (340 mi.)

(a) Max. design flood for this dam alone, considering that other dams do not exist.

MEKONG RIVER

Summary of basic data

Total drainage area	795,000 sq. km.	307,000 sq. mi.
Total length of river	4,200 km.	2,600 mi.
Mean annual precipitation		
Upper basin — Yunnan	1,000 mm.	40 in.
Middle basin — Laos, Thailand, Cambodia ..	1,750 mm.	70 in.
Lower basin — South Viet-nam	1,500 mm.	60 in.
Maximum flood discharge at Kratie (estimated)	60,000 c.m.s.	2,100,000 c.f.s.
Mean annual discharge (probable)	15,900 c.m.s.	560,000 c.f.s.
Minimum discharge at Pnom Penh (1950)	1,700 c.m.s.	60,000 c.f.s.
Mean annual run-off	500,000,000,000 cu. m.	400,000,000 ac. ft.
Maximum silt content	0.03 %	
Average silt content	0.016 %	
Mean annual silt run-off	80,000,000 tons	

General Features of the River Basin

The Mekong River (see figure 20) rises in the snow-covered mountain ranges of the Tang-Ku-La Shan of the great plateau of Tibet at an elevation of over 5,000 m. It flows generally in a southerly direction along the mountain ranges in China and through the Indochinese peninsula to the South China Sea. The total length of the river is 4,200 km. (2,600 mi.) and the total drainage area is 795,000 sq. km. (307,000 sq. mi.). The discharge of the Mekong varies from 1,700 c.m.s. to 60,000 c.m.s. (60,000 to 2,100,000 c.f.s.). Unsatisfactory from a navigation point of view, the Mekong has not permitted access on it to South China as its general direction promises. Lower down towards the river mouth the Mekong has six branches which intersect its delta.

Descending from the snow-clad slopes of Tibet, the Mekong flows southward through a little known and narrow stretch between the upper reaches of the Yangtze and the Salween. It runs through the Chinese provinces of Sikang and Yunnan under the name of Lan Tsiang River. In Yunnan it widens occasionally forming fertile valleys which are separated from each other by narrow gorges, only 30 m. (100 ft.) wide.

The Mekong is still a torrent when it rushes into Laos, 2,593 km. (1,620 mi.) from the sea, in spite of its width of 400 m. (1,300 ft.). Crossing the Indochinese frontier till it reaches the plateau land where the Mekong becomes the boundary between the Indochinese Federation and Thailand, the river course takes a few large turns with its flow confined in a narrow gorge with vertical banks. Rapids are common in this stretch. The river then flows southward across plateau land, which has an elevation of from 100 to 200 m. (330 to 660 ft.) above sea level, until it reaches Kratie, 550 km. (340 mi.) from the sea. From Kompong Cham, a little distance below Kratie, to Phnompenh, the general topography of the alluvium is ridges

of higher land formed along river banks and behind a vast area of depressions known as "Bengs". Flood water rushes through these numerous canals to the large areas behind and spreads into a vast sheet. Most of Cambodia's population is concentrated along the banks of the river.

The actual delta of the Mekong may be said to begin at Phnompenh. The river divides here into two branches, the Mekong to the east and the Bassac to the west. Where the branches bifurcate is located the Tonle-Sap, the overflow channel to the Great Lake, which acts as a huge detention reservoir. During the flood season the area of the lake increases from 3,000 sq. km. to 10,000 sq. km. (1,100 to 3,900 sq. mi.) and the depth from 1 to 10 m. (3 to 33 ft.). The volume of flood flow diverted from the Mekong, together with the run-off from the small rivers flowing directly into the lake, is estimated at about 30,000 to 40,000 million cu. m. (24 to 32 million ac. ft.). This has a tremendous effect in moderating the flood flow downstream.

From Phnompenh down to Chaudoc, or to the border of Cambodia and South Viet-Nam (Cochin-China), the general topography is similar to that from Kompong Cham to Phnompenh. Higher ridges exist along both banks of the river, and behind them are depressions connected to the river by numerous canals which lead the flood flow into the depressions. The higher ridges along the river are only submerged during extraordinary floods.

Lower down from the South Viet-Nam border to the sea, for a distance of approximately 180 km. (110 mi.), is a vast and extraordinarily flat plain with a slope of only 1:100,000. From the border to a distance of 120 km. (75 mi.), the flood flow spreads over both banks of the Mekong and Bassac rivers to a width of 180 km. (110 mi.). On the eastern bank of the Mekong is the Plaine des Jones, about one million hectares in area, bounded by the West Vaico

River on the east. Due to unfavourable drainage conditions in the area, half of the land remains unutilized. West of the Bassac River, a deeply flooded area exists on the upper portion south of Chaudoc, where floating rice is grown. Artificial canals from the Bassac to the Gulf of Thailand drain off part of the flood flow, around 5,000 c.m.s. (176,000 c.f.s.).

The flat plain, some 60 km. (38 mi.) from the coast, is under the influence of tidal movement of the China Sea. Inundation from the river flow, when backed up by the high tide, can reach a depth of 30 to 40 cm. (1 ft.). Small bunds are constructed on the rice fields to control the water.

The mean annual rainfall of the upper basin in Yunnan is 1,000 mm. (40 in.). In the middle basin of the Mekong in Laos and Cambodia, it is 1,750 mm. (70 in.) and in the lower plain of South Viet-Nam it is 1,500 mm. (60 in.). An annual maximum of 7,970 mm. (312 in.) was recorded in 1923 at Kaskong and the daily maximum was 650 mm. (25.6 in.) at Doc-Phu in 1926. In the middle and lower basin, the monsoon regime divides the year into a rainy season in summer (South-West Monsoon) and a dry season in winter. The water level rises from the lowest level at the beginning of June and attains its maximum height in September-October, then falling rather rapidly from October to January, and finally reaching its lowest level once again in May. Worthy of note is the detention effect of the Grand Lake which equalizes the sharp fluctuations from upstream, and maintains a remarkable regularity of flow downstream of Phnom-penh every year. The maximum discharge at Kratie is estimated at 60,000 c.m.s. (2,100,000 c.f.s.), while the mean annual run-off is estimated at more than 500,000 million cu. m. (400 million ac. ft.).

The silt content of the Mekong is rather low. During the high flood period of September, the silt content at Phnom-penh is only from 0.025 to 0.03 per cent. The annual silt run-off can be estimated at 80 million tons or 53 million cu. m.

Floods and Flood Damage

Above Kratie, where the river flow is confined in gorges or well-defined valleys, floods merely raise the river stage. The spreading of flood flow begins downstream of Kompong Cham and covers an area of 3 to 4 million ha. (7.4 to 9.9 million ac.) in Cambodia and South Viet-Nam. The extent of the annually flooded area is shown in figure 20.

The people of this region have adapted themselves very well to the flood conditions. In Cambodia, from Kompong Cham to the South Viet-Nam border, houses are built on the strips of higher land along the river banks usually on tall piles. They are thus well above the highest flood level. Behind the land side is another strip which, being situated on the slope of the ridge, is not subjected to normal flooding.

It is an area of dry cultivation. Still further back is a considerable area of paddy fields usually cultivated after floods. Behind this area lie the depressions in which fish-rearing is carried on. In fact, floods, except those of extraordinary magnitude, are considered beneficial because of their deposition of fertilizing silt, the transport of shoals of fish, and because during the floods wild animals seek a haven in the unaffected areas which become rich hunting reserves during the dry season. During the dry season, too, timber is felled in the forests and the logs are tied in rafts. The flood waters later transport them down river to the timber mills.

Down to South Viet-Nam, south of Chaudoc, the area is flooded to a depth of from 3 to 5 m. (10 to 16 ft.). Here a special kind of rice, floating rice, is grown. The roots remain in the soil and the stem lengthens with the rising water as long as the latter does not exceed 10 cm. a day. Downstream near the coast, in a belt 60 km. (37 mi.) along the coast, inundation due to flood flow reinforced by high tide is only 30 to 40 cm. This provides ideal conditions for cultivation of ordinary rice.

Such favourable conditions can be attributed to the influence of the Grand Lake which absorbs and moderates the flood flow by acting as a storage or detention reservoir. The annual fluctuation of the highest water level and the period of flood occurrence might not, however, exactly suit plant growth. For example, if floating rice is planted and the flood level remains low, a very poor crop is the likely result. In this case semi-floating rice will suit the conditions better. If ordinary or semi-floating rice is planted, and the flood level is high, the crops will be lost entirely. In areas where early rice is planted after the first rains at the end of April, if floods occur early young plants will be killed by the sudden submersion.

From 1894, when records of gauge heights were first kept at Phnom-penh, up to 1943, seven extraordinary floods occurred in 1894, 1904, 1907, 1923, 1929, 1937 and 1939 which destroyed crops of those years. The frequency of occurrence of such floods is approximately once every nine years.

The area damaged by such extraordinary floods amounted to 1 million ha. (2.5 million ac.) out of a total cultivated area of 800,000 ha. (2 million ac.) in Cambodia, and 2,300,000 ha. (5.7 million ac.) in South Viet-Nam. Distributed over the period of flood occurrence, the average annual damage would affect 111,000 ha. or roughly 3.6 per cent of the total cultivated area.

Statistics of flood damage to crops in 1937 and 1939 indicated that, on an average, 50 per cent of the standing crops were lost in the floods. Figures for other direct and indirect losses are not available. Taking the average yield of paddy as one ton per hectare, the unit loss of crops would be half a ton and the average annual damage to crops would work

out at 55,600 tons of paddy. When assessed at the present free market price of 40 U.S. dollars per ton of paddy, the average annual flood damage would be 2.24 million U.S. dollars.

This relatively sparsely populated but fertile area, which has a density of only 100 per sq. km., is one of the important rice-exporting areas of the region. Surplus rice is generally available for export even after a serious flood, which has destroyed part of the crops. The following figures of exports of rice after the floods of 1923, 1929 and 1937 also indicate the extent of flood damage to crops:

		Tons		Tons
Exports of rice :	1923	1,399,500	1929	1,471,600
	1924	1,230,200	1930	1,121,600
Decrease of export :		169,300		350,000
Exports of rice :	1937	1,529,350		
	1938	1,064,800		
Decrease of export :		464,550		

Total population affected by floods is estimated at half a million, which includes that of the provinces of Longxuyen-Chaudoc, Rachgia, Hatien and of Cambodia and Laos.

Flood Control Activities and Projects

Except for extraordinary floods, which occur once in every nine years on an average, normal floods are considered beneficial to rice crops. After the people adapted themselves to the flood conditions, continuous embankments along the Mekong basin were considered unnecessary and are today not to be found anywhere in the area, except a short length recently completed near Choeung Prey (between Mekong and the Tonle Sap, 10 km. from the right bank of the Mekong), protecting an area of 3,000 ha. (7,400 ac.).

As the growth of rice depends entirely on the natural stream flow, flow prediction work is considered of vital importance. Up to now, no fully satisfactory warning system has been devised.

Projects now being undertaken on the lower plain are described below :

(1) Cambodia.

The depressions along the Mekong are low lands which are flooded every year. They are connected with the main river by numerous canals. It is proposed

to construct sluices at these canals and to control the in and out flow. The fertile silt-laden water during floods enters the depressions and is emptied when the river stage recedes, thus permitting a crop of early rice and sometimes a second crop of maize.

(2) South Viet-Nam.

(a) Improvement of Plaine des Jones. This plain about 930,000 ha. (2.4 million ac.) in extent, is situated on the eastern banks of the Mekong and is bounded by the West Vaico River. The area is flooded by the high water of the Mekong and suffers from inadequate drainage through the Vaico River. Water remains stagnant and the soil becomes salt-impregnated.

Rain very often synchronizes with the flood and aggravates the situation. The depth of inundation is from 2 to 3 m. (6 to 10 ft.). Nearly half of the area becomes wasteland and cultivation is carried out only on the higher land around the boundaries.

It is not possible to increase the discharge capacity of the Vaico River in order to release the flood flow. The practical solution is to dike the area with embankments from the flood flow of the Mekong at a distance of 30 km. (18 mi.) east of and parallel to the main river. Apart from the elaborate canal system, the drainage of this area could be greatly improved so as to be made suitable for growing different varieties of rice. Confining the flood flow of the Mekong at the eastern bank should raise the maximum flood level, according to calculation, about 0.15 m. (0.5 ft.) which is not considered excessive.

(b) Improvement of Transbassac. The Transbassac is the area lying between the Bassac and the sea. It has a very flat slope of 1:100,000. Starting with the South Viet-Nam border this area can be divided into three zones. The first comprises the deeply flooded area between Chaudoc-Longxuyen and the Gulf of Thailand about 400,000 ha. (1 million ac.) in extent. Floating rice is grown here and no flood protection is afforded at present. The middle zone, where natural conditions are very favourable for drainage and irrigation, is about 480,000 ha. (1.2 million ac.) in extent. It is proposed to improve the conditions by constructing a small embankment running roughly parallel to the Bassac River for the purpose of controlling the height of inundation and, if necessary, to initiate irrigation by low head pumping from the Bassac River. This will secure the best growing conditions for rice. The third zone, comprising land near the sea, is often endangered by salt water. Small creeks carrying salt water have been closed and sluices constructed which permit, depending on the tidal stage, the in and outflow of fresh water.

PAMPANGA AND AGNO RIVERS

The most highly developed agricultural region in the Philippines is the Central Plain of the island of Luzon lying between latitudes 15° and 16° north of the equator. This plain, aptly termed the rice granary of the Philippines, is bounded on the north by the Caraballo Mountain Range and the Lingayen Gulf, on the east by the Sierra Madre range along the Pacific coast, on the west by the Zambales mountains along the China Sea coast, and on the south by the Manila Bay and the coastal plain of Manila. Two river systems drain this region, namely: the Pampanga River traversing the eastern and southern portions, and the Agno River which drains the north-western areas (see fig. 21).

Pampanga River

General description of the river basin

The watershed of the Pampanga River covers an area of 8,580 sq. km. (3,220 sq. mi.), extending over the southern slopes of the Caraballo mountains, the western slopes of the Sierra Madre range and the major portion of the Central Plain, which slopes down in a general north to south direction to the shores of the Manila Bay. The total length of this river from its source in the Caraballo range in the north, to its mouth in the Bay is 263 km. (163 mi.).

The elevation of the highest peak of the Caraballo range at the headwaters of the Pampanga River is 1,798 m. (5,700 ft.), the average height of the range being 650 m. (2,130 ft.) above mean sea level. The mountain slopes are covered by thick growths of tropical vegetation, except for isolated sections near outlying villages where clearings have been made, but these are of comparatively small extent.

At Rizal, Nueva Ecija, the river issues from the hills into the central plain with the river bed at elevation 73 m. (240 ft.). During the rainy season, the flow is heavily loaded with sand, gravel and boulders — products of natural erosion in the mountain section — which, encountering the suddenly much flatter slopes of the plain, are deposited in the debris cone south-east of Rizal. For a distance of some 30 km. (19 mi.) the wide, shallow, and unstable channel, hugs the western slopes of the Sierra Madre range, following a southerly course, then it curves westward and south-westward, moving farther into the plain and traversing the rich ricelands of Cabanatuan, Sta. Rosa, Jaen, San Isidro, and Cabiao. A large number

of tributary creeks and streams, draining the hills on the east, join the Pampanga River between Rizal and Cabiao, the largest of which is the Penaranda River, whose waters have been harnessed for irrigation.

From Cabiao, the river channel continues on a south-westward course until it hits Mt. Arayat, an extinct volcano (peak elevation 1,030 m. or 3,400 ft.) standing alone in the centre of the plain. Here the Rio Chico, biggest tributary of the Pampanga River, joins it, the elevation of the river bed at the junction being 5 m. (16.4 ft.) and of the natural ground surface near the banks 8 m. (26 ft.) above sea level. To the north, immediately above the junction of these two streams, with the Rio Chico meandering through its centre, lies a low water-logged area known as the San Antonio swamp covering an area of 15,000 ha. (37,000 ac.) and with an average elevation of 6 m. (20 ft.). From the confluence, the main channel follows a southerly direction passing Arayat, Candaba, San Luis, Apalit and Calumpit. Along this stretch, to the east, lies the Candaba swamp covering an area of 30,000 ha. (74,000 ac.) with an average elevation of 4 m. (13 ft.) above sea level.

At Calumpit, another big tributary, the Angat River, joins the main channel. From there the latter follows a southward course toward the Manila Bay. At about the latitude of Masantol, a distance of 20 km. (12.4 mi.) from the Bay as the crow flies, the main channel divides into two streams and these in turn branch and re-branch again and again to form a network of sluggish, tidal streams which ultimately empty into the Bay through numerous mouths.

Floods and Flood Damages

The mean annual rainfall over the watershed is 2,500 mm. (98.5 in.). The average depth of rainfall over the watershed during periods of maximum precipitation are as follows:

Maximum	1-day rainfall	191 mm. (7.5 in.)
—	2 — —	307 mm. (12.1 in.)
—	3 — —	346 mm. (13.6 in.)
—	4 — —	366 mm. (14.4 in.)
—	5 — —	404 mm. (15.9 in.)
—	6 — —	441 mm. (17.4 in.)
—	7 — —	467 mm. (18.4 in.)

Floods occur during the typhoon season from June to November, when the South-West monsoon prevails over the Islands. Floods are caused by heavy

precipitation accompanying typhoons or cyclonic depressions originating in the ocean regions south-east of Mindanao and moving generally in a north-westerly direction and disappearing ultimately into the continent. Destructive floods occur when the typhoon path crosses the watershed or passes north or north-east of it. When the typhoon path passes south of the watershed, precipitation is comparatively small and no floods of consequence occur.

At Calumpit the river is 170 m. (560 ft.) wide with an average depth of 6 m. (20 ft.) below bank level. At maximum flood stage the channel disappears in the wide expanse of the flood plain extending over a width of some 30 km. (19 mi.), the flood flow sweeping southward into the bay. The peak flood discharge at this point is estimated at 14,000 c.m.s. (495,000 c.f.s.). Inundations last from three days to two weeks at depths ranging from 0.5 to 3 m. (1.6 to 10 ft.).

The debris load of the river is destructive in the reach between Rizal and Cabanatuan. Below the latter, the silt load is comparatively light and creates no problem.

Destructive floods are an annual occurrence in Central Luzon. They may occur anytime during the typhoon season between June and November. From December to May there is very little rainfall and the fields are left idle except for comparatively small areas which are irrigated. Floods which occur in June or July easily destroy the newly-planted seedlings and it is a frequent occurrence for farms to be replanted twice or more times. Floods which occur in October and November damage and destroy ripened crops, and because precipitation in the ensuing months is not sufficient to support another planting, such late floods reduce the annual productivity of unirrigated lands to very low levels.

In addition to crop destruction, damages to roads, bridges, buildings, fishponds and to agricultural land itself, amount to large sums. In the debris cone between Rizal and Cabanatuan, wide areas are rendered useless every year by the deposition of sand and gravel. The average annual flood damage is conservatively placed at Peso 3,000,000 or U.S. \$ 1,500,000.

Flood Control Activities

The flood control scheme consists of a comprehensive system of earth dikes, cut-off channels, and relief floodways, supplemented by the utilization of the San Antonio and Candaba swamps as retarding basins. To accelerate the flow of waters into the Manila Bay, two major relief floodways are contemplated

namely: (1) the Bebe-San Esteban Floodway, 200 m. (660 ft.) wide and 7 km. (4.4 mi.) long and (2) the Hagonoy Floodway 200 m. (660 ft.) wide and 6.5 km. (4.0 mi.) long. Four other cut-off channels with an aggregate length of 4.5 km. (2.8 mi.) are intended to straighten the meandering course of the river below Calumpit. The Sulipan-San Miguel cut-off providing a floodway of 350 m. (990 ft.) has already been opened, but has not been completed to designed dimensions.

Both banks of the Angat River will be protected by setback lines of levees. The levee on the north bank will be provided with a fuse plug section to allow direct discharge into the Candaba swamp during extreme floods.

A massive earth dike will be constructed, to protect the large area south of Mt. Arayat, starting from the downstream end of the Bebe-San Esteban Floodway and following the west bank of the Pampanga river through Apalit, San Luis and Arayat and ultimately connecting with the high slopes of Mt. Arayat. The meandering course of the stream between Cabiao and Cabanatuan will be straightened by a series of cut-offs, and the flood flow confined by earth dikes on both banks. A long spillway will be provided in the west dike to allow direct flow into the San Antonio swamp during extreme floods. A total length of 260 km. (162 mi.) of earth dikes, 6 m. (20 ft.) wide at the top, side slopes at 1:3 and ranging in heights from 3 to 6 m. with a freeboard of 1 m. (3.3 ft.) above the design flood, is proposed.

Construction of the flood control system is under the Pampanga River Control Project which was organized in 1939. Up to the present, 80 km. (50 mi.) of earth dikes have been constructed. The Bebe-San Esteban Floodway, the Sulipan-San Miguel Cut-Off and the Cabiao-Candaba Floodway, which provide direct connection between the San Antonio and Candaba swamps, have been opened but are not yet completed to the designed dimensions.

The project is designed to protect an area of 2,500 sq. km. (970 sq. mi.) at an estimated cost of Peso 25,000,000.

Agno River.

General description of the river basin

The Agno river system (see figure 21) with its principal tributary, the Tarlac river, drains the north-western portion of the central plain of Luzon. The watershed area is 4,794 sq. km. (1,890 sq. mi.) and the length of the river from its source in the Cordillera mountains in the north to its mouth in the

Lingayen Gulf is 272 km. (169 mi.). The highest peak at the headwaters has an elevation of 2,034 m. (6,650 ft.), the average height of the mountain range being 1,400 m. (4,600 ft.) above sea level.

The mountain section is covered mostly with tropical forests. At higher elevations vegetation of temperate climates, like pine, abound. The topography is more rugged and the slopes more abrupt than those of the Caraballo range at the headwaters of the Pampanga, hence the river carries a heavier load of debris as it comes out of the rocky gorge at San Manuel, and issues forth into the plain. Immediately below the gorge at San Manuel, the river channel is very unstable, changing from one course to another almost every year, so that several channels are visible, all of them wide, shallow and filled with gravel and large boulders. The river follows a southerly direction down to the latitude of Tayug, then it veers to the south-west through Villasis and Bayambang into the Poponto swamp where it is joined by the Tarlac river. From the junction of the two rivers, the main channel moves north-westward skirting the eastern slopes of the Zambales mountain range and ultimately discharging into the Lingayen Gulf.

The Tarlac River draining an area of 1,076 sq. km. (415 sq. mi.) carries a heavy load of sand most of which is deposited in the Poponto swamp.

Below the junction of the Tarlac and the Agno the flow is relatively free of silt. Upstream of Bayambang the main channel is wide and highly unstable traversing an alluvial region of soft, loose mixture of loam and sand. The banks are easily eroded and the channel, choked by a high railroad embankment, used to meander acutely between Bayambang and Villasis, until a series of cut-offs straightened the course more or less to its present condition. But the vulnerability of the soft banks to erosion by the swift currents renders the direction of flow erratic and unpredictable. Training the river to remain within the proposed levees will be a difficult and expensive project. Downstream of Bayambang the river channel is well defined and deep, the banks comparatively firm and stable. The action of tidal currents and sand drifts along the shore of the Lingayen Gulf tend to push the mouth of the river to the west. Several mouths to the east have been abandoned and at present a new one is being formed in the vicinity west of Bugallon.

Floods and Flood Damages

The watershed above Villasis receives heavy rainfall from the South-West monsoon. The average

annual rainfall here is 3,800 mm. (150 in.). In Baguio, near the headwaters, the highest recorded 24-hour rainfall (July 14, 1911) was 1,272 mm. (50 in.). The watershed of the Tarlac river has a mean annual rainfall of 3,050 mm. (120 in.). Below the junction of the two rivers at Wawa, the estimated peak discharge is 10,000 c.m.s. (353,000 c.f.s.).

Destructive floods occur every year lasting from two to five days. The currents are swift and much of the floodwaters sweep across the plain in a general north-westward direction into the Gulf. Intense flood producing rains come with typhoons or cyclonic depressions between June and November with the South-West monsoon dominating the atmosphere. Exceptionally big floods occurred in the three successive years 1935, 1936, and 1937, causing severe damage to crops, roads, bridges and various improvements, amounting to Peso 14,700,000 (U.S. \$ 7,350,000).

Flood Control Activities

The Agno River Control Project was organized in 1939. Previous to this no comprehensive study of the flood problem as a whole had been made and dikes were constructed by local authorities without benefit of an over-all plan. The main features of the flood control scheme now being constructed are as follows :

1. Straightening the river course from its mouth to Villasis by a series of cut-off channels.
2. Construction of earth dikes along the east bank of the river from its mouth to the low hills of Bayambang.
3. Construction of earth dikes on both banks of the river from Rosales to Bayambang, the dike on the right bank to be continued up to the gorge at San Manuel.
4. Utilization of storage capacity of the Poponto swamp to retard the flood flow.
5. Construction of dikes on the east bank of the Tarlac River from the Argana Bridge at Tarlac to the latitude of Moncada.

The total length of the proposed levees is 167 km. (104 mi.) with a top width of 6 m. (20 ft.) and an average height of 5 m. (16.4 ft.). Sixty-seven km. (42 mi.) of earth dikes have been completed to-date and ten cut-off channels excavated with an aggregate length of 18 km. (11 mi.). The whole project when completed is expected to protect an area of 1,800 sq. km. (700 sq. mi.) at an estimated cost of Peso 17,000,000 (U.S. \$ 8,500,000).

PEARL RIVER

Summary of basic data

Total drainage area 434,500 sq. km. (167,000 sq. mi.)

	WEST RIVER AND CANTON DELTA				EAST	RIVER
Drainage area	348,300 sq. km.	134,400 sq. mi.	49,000 sq. km.	18,900 sq. mi.	37,500 sq. km.	14,400 sq. mi.
Length of river	1,790 km.	1,111 mi.	500 km.	310 mi.	450 km.	279 mi.
River slope	1:37,000					
Average annual precipitation	1,532 mm. (Wuchow-Kaoyao)	59.7 in.	1,650 mm. (Lupao-Sanshui)	64.3 in.	1,650 mm.	64.3 in.
Maximum flood discharge (estimated from 1915 flood level)	71,500 c.m.s. (Wuchow)	2,520,000 c. f. s.	15,500 c. m. s. (Lupao)	547,000 c. f. s.	6,070 c. m. s. (Shihlung)	214,000 c. f. s.
Average annual discharge	7,939 c.m.s. (Wuchow)	280,300 c. f. s.	1,650 c. m. s. (Lupao)	58,200 c. f. s.	1,260 c. m. s. (Shihlung)	44,490 c. f. s.
Minimum discharge	938 c.m.s.	33,800 c. f. s.	220 c. m. s.	7,760 c. f. s.	431 c. m. s. (Shihlung)	15,200 c. f. s.
Average annual run-off	246,930 million cu. m. (Wuchow)	200million ac. ft.	52,000 million cu. m. (Lupao)	42 million ac. ft.	39,600 million cu. m. (Shihlung)	32 million ac. ft.
Average annual run-off per unit area	.0254 c.m.s./sq. km.	2.3 c. f. s./sq. mi.	.0337 c. m. s./sq. km.	3 c. f. s./sq. mi.	.0336 c. m. s./sq. km.	3 c. f. s./sq. mi.
Maximum silt content	.038 % (Wuchow)		.0108 % (Chuekiang)		.0307 % (Huyang)	
Average silt content	.0113 % (Wuchow)		.0041 % (Chuekiang)		.0224 % (Huyang)	
Minimum silt content	.003 % (Wuchow)				.0182 % (Huyang)	
Average annual silt run-off	27,946,000 tons (Wuchow)		21,200,000 tons (Sanshui)			
Coefficient of run-off	52.6 %		76.62 %		58.44 %	

General Features of the River Basin

The Pearl River basin (see figure 22) is situated roughly between latitudes 21° and 27° N and longitudes 102° and 116° E, and is separated from the basin of the Yangtze by a high mountain chain known as Nanling Cordillieres, stretching eastward from Central Yunnan to the East China Sea. It is subdivided into three minor basins; the West River, the North River and the East River. Flowing down to the delta the three rivers are so connected that flood control for all has been integrated and flood preven-

tion is of greater importance particularly in the well-developed delta than elsewhere. The name Pearl River is used to denote the entire system. The West River is the longest and its watershed the largest, while the North and East Rivers are of about equal size. No lake of any great size exists in the basin. The watershed of the whole Pearl River basin covers about 434,800 sq. km. (167,700 sq. mi.), with the West River occupying 339,000 sq. km. (130,800 sq. mi.) or 78.1 %; the North River 49,000 sq. km. (18,900 sq. mi.) or 11.2 %; the East River 37,500 sq. km. (14,400 sq. mi.) or 8.6 %, and the Canton Delta 9,300 sq. km. (3,600 sq. mi.) or 2.1 %.

The population of the Pearl River basin totals 34,620,338 according to the 1946 census. The population density within the basin averages about 80 per sq. km. (207 per sq. mi.) and varies widely because of unequal distribution. It increases gradually in the lower delta, with the maximum concentration there, as is generally the case. Here the population totals 9,924,126 in 9,300 sq. km. (3,600 sq. mi.) giving a density of 1,056 per sq. km. (2,750 per sq. mi.).

The area under cultivation in the low-lying, fertile delta is about 5,587 sq. km. (2,156 sq. mi.) out of the total of 9,300 sq. km. (3,600 sq. mi.), and yields from two to three crops annually, owing to the very favourable climatic conditions. In the upper valley, agricultural activity is confined to the narrow and short strips of cultivable land along the river, or on isolated plains where water is available. Mountains in the upper basin, especially of the East River, are bare. The total acreage under cultivation of the basin amounts to 48,950 sq. km. (19,600 sq. mi.), including that under rice, sugar, cotton, vegetables, orchards, tea, cereals and other crops. Land utilized averages less than 10% in Kwangsi against 20% in Kwangtung, and over 63% in the delta. No details for forests are available.

The rivers in the delta have a total navigable length of about 1,000 km. (620 mi.) for steamers from 100 to 500 tons. During high water, vessels of 150 tons can sail up to 90 km. (55.8 mi.) above Kweiping on the West River, and those of 700 tons can reach Wuchow from Hongkong. Motor boats may travel as far as Liuchow. On the North River, craft with a small draft can sail 120 km. (74.5 mi.) up to Chingyuan and up to Chuekiang in the flood season. Navigation on the East River is possible up to 160 km. (99.3 mi.) from Canton and during high water motor boats may reach Loulung. Sea-going vessels can reach Huangpo harbour 12 km. (7.4 mi.) east of Canton, throughout the year.

The West River

The West River rises in the high plateau of Yunnan, at an altitude of about 3,000 m. (9,840 ft.) above sea level. After running for some distance along the Kweichow-Kwangsi border, it takes a south-easterly course until Sanshui, on the Pearl River delta, where it joins the North River with a short cross channel, and from there swings south to the South China Sea. The upper reach of the river is merely a swift torrent pouring between gorges. Cutting through the hilly region, the river leaves the gorge at Kaoyao about 140 km. (87 mi.) from the outlet to the sea. There are two more isolated gorges in the delta known as Lingyang and Maco. One is situated below Kaoyao

and has a length of 7 km. (4.3 mi.) with the narrowest section 360 m. (1,181 ft.) wide and 77 m. (252 ft.) deep. The other is situated below the Sanshui junction with the North River and narrows to about 520 m. (1,706 ft.) in width. This gorge has a very important bearing on the flood level in the plain above, owing to its constriction of the combined flood discharge of the two rivers. The channel then narrows again at Fooweng and a cataract lies along the navigable channel at Kanchu.

The river then divides into many channels with the largest running southwards, and the minor ones running east to the sea.

The North River

The North River's twin sources, which rise in the mountains north of Kwangtung, join at Chuekiang. It runs for some 500 km. (310 mi.) before emptying into the sea. The river above Chuekiang is a swift torrent rolling down the mountains, and below it is contained in a channel cut through the hilly country as far as Chinyuan, where it emerges from the Feilai gorge on to the Pearl River delta. Below Sanshui junction, it subdivides into several interconnected watercourses, like the West River, and runs to the sea more or less parallel to the main channel of the latter. The flow at Sanshui junction is reversed when the West River has a higher water level than the North River. Kanchu channel provides another main connection between the West and North Rivers in the delta.

The East River.

The East River originates in the mountains along the Kwantung-Kiangsi border and runs for 450 km. (279 mi.) to the sea. The upper valley is similar to that of the North River. The East River flows into the Canton delta at Huiyang and bifurcates at Shihlung. Both these branches again subdivide into a number of watercourses, as in the case of the West River, and form smaller deltas below Shihlung. Tributaries of the East River are comparatively short but contribute much to the flood discharge of the East River on account of their steep slope, and heavier rainfall in the basin.

The Pearl River in the Delta.

The Pearl River itself is a small river which rises some 80 km. (50 mi.), north-west of Canton and takes a south-westerly course until it joins Lupao creek, and then turns south to Canton. It divides into two branches in front of the town. The northern branch, or front reach, is more important to Canton as far as navigation is concerned, although it has an

average width of 100 m. (328 ft.) and a depth of not more than 2 m. (6.5 ft.) over shoals. It deepens gradually to over 7.3 m. (23.9 ft.) at Huangpo Harbour. The back reach, or southern branch, on the other hand, has a width of over 310 m. (1,010 ft.) and a depth of not less than 4 to 4.3 m. (13.1 to 14.1 ft.) over shoals. The two channels join at Huangpo Harbour. After Huangpo the river widens considerably and the navigable depth increases to more than 8.8 m. (28.8 ft.) at Boca Tigris. Generally, in low water, vessels of 4.7 m. (15.5 ft.) draft may sail up to Huangpo, and those of 2.6 m. (8.5 ft.) up to Canton, while during spring tide the depth increases to 7.2 and 4.5 m. (24 to 14.7 ft.) respectively. In high water, the river is fed principally from the North River, and via the connection at Sanshui junction from the West River, apart from the water from its own basin. During the dry season the supplies from the two rivers are completely cut off, and the water from its own watershed is also scanty. The Pearl River then acts more as a tidal channel.

The rivers in the delta are connected by a network of canals, of which no detailed or systematic survey has yet been made, except for the major ones.

Dikes have been constructed along the lower course of the West, North and East Rivers and on the Pearl River delta. The total length of dikes in the entire Pearl River basin amounts to 1,300 km. (807 mi.) and protects an area of about 240,000 ha. (594,000 ac.), which constitute the most fertile land of the basin. Embankments along the main river course and protecting large areas are termed major or official dikes, and their construction and maintenance are financed by Government. Others are termed minor or private dikes, and are constructed and maintained under Government supervision by villagers who benefit from them. Some of the dikes which were considered minor ones previously are now counted major ones. Embankments are usually from 2 to 7 m. (6.5 to 23 ft.) in height, and from 2 to 4 m. (6.5 to 13 ft.) in top width.

The average annual rainfall in the delta, and along the coast in Kwangtung, ranges from 1,750 to more than 2,000 mm. (68 to 78 in.). In the areas further inland, it decreases from 1,750 to 1,500 mm. (68 to 58.5 in.), and in the Yunnan plateau, it is about 1,000 mm. (39 in.). May to September is generally the wet season, with the heaviest rainfall usually in June, when more than 60 % of the annual precipitation is likely to occur. December and January are the months of least rainfall, receiving usually less than 2 % of the annual precipitation.

Tropical typhoons occur throughout the year, with July to October the months of heaviest fre-

quency. Typhoons are specially common in August and September, and contribute to the heavy rainfall by coinciding with the South-West monsoon. The maximum precipitation in 24 hours has a wider variation as far as magnitude and time of occurrence are concerned, because precipitation is mainly the result of typhoons or thunderstorms which are uncertain and irregular. Rainfall in the delta is heavier, a precipitation of 100 mm. (3.9 in.) within 24 hours being common, with a recorded maximum of 320 mm. (12.4 in.)

The hydrographs of the three rivers follow the pattern of rainfall with the low water season from November to March, and the high water season from the end of May to September.

Floods and Flood Damage

The comparatively low-lying alluvial strips in the upper course of the West River above Wuchow are subject to flood in years of very high water. The Canton delta is threatened by the floods of the three rivers, even in years of normal flow.

High flood in the Pearl River basin is the result of heavy rainfall in abnormally "wet" years. The flood discharge of the three rivers in such years is exceedingly high, and is beyond the capacity of the channels to hold. The section of the lower West River in the delta is narrow at several points. This inevitably backs up the flood level upstream of the contractions and contributes to a further rising of the high flood level of the rivers. Silting is reducing the capacity of both the lower North River and East River in the delta annually. Moreover, the time of concentration in the basin of all the three rivers is short, and the flow in the delta is retarded by tides. A combination of the above-described causes results in the annual flooding of the low-lying land along the river, as well as in the delta. Dikes have been the only means of protection against flood in the delta since early history, and were constructed apparently without the comprehensive requirements of an overall flood prevention scheme. The existing dike system, although remodelled and strengthened lately, is still incapable of resisting high floods such as occurred in 1915 or 1947, and when it breaches in the delta, the inundation continues till the low water season, as the accumulated water in the low-lying agricultural land can find no outlet, and is forced to stagnate.

Data on the damage of the more serious floods occurring in recent years are available and listed in the following table :

Flood damage of the Pearl River delta

Year	Area inundated in hectares				Remarks
	West River	North River	East River	Total	
1915	342,000	196,000	250,000	788,000	highest recorded flood
1922	—	—	100,000	100,000	
1924	180,000	85,000	—	265,000	
1926	83,500	—	—	83,500	
1931	63,000	162,400	250,000	475,400	
1947	275,000	75,400	179,000	529,400	serious flood
1949	54,850	—	—	54,850	
Aggregate area				2,295,750	
Average annual area inundated (1915-1949 inclusive)				65,600 (164,000 acres)	

The flood of 1947, next in magnitude to the highest recorded flood of 1915, caused 5,202 dike breaches for a total length of 443 km. (275 mi.). The total population affected by that flood was estimated at 4,230,000. Details of the damage of the 1947 flood (1) rated in CNC \$ pre-war value (1936) are listed below :

Crops lost	66,900,000
Buildings	32,100,000
Farm implements	4,590,000
Work animals	1,200,000
Domestic animals	17,160,000
Total	CNC \$ 121,950,00

Based on this figure, the damage per unit area was CNC \$ 230 per hectare. If the average value from 1915 to 1949 is taken, the average annual area subject to inundation would be 65,600 hectares (162,000 acres) and the average annual flood damage would amount to CNC \$ 15,000,000, or roughly US \$ 4,500,000.

Flood Problem and Proposed Plan of Flood Control

Measures for flood control as proposed by the Pearl River Engineering Bureau are as follows :

(1) *Strengthening and Remodelling of the existing Dike System.*

As flood prevention in the delta depends mainly on the existing dikes which have already been seriously damaged during the war and the subsequent floods of 1947, their overall strengthening has been considered essential. Adjusting the alignment of the existing dikes which, in some localities are obstructing the flood flow, is also considered necessary.

(1) Source : Report of the Kwangtung Flood Relief Commission, 1948.

(2) *Detention and Diversion of Flood*

The present dike system appears incapable of holding a flood comparable in magnitude to that of 1915, which occurs approximately once in a century. Detention or storage reservoirs in the headwaters are proposed for reducing the flood flow. An estimate indicates that a total storage capacity of approximately 5,000 million cu. m. (4 million ac. ft.) would lower the flood level by 1.5 m. (4.9 ft.) in the delta. The Pearl River Bureau proposed the construction of some ten large reservoirs in the headwaters to regulate the flood flow, as well as to develop water-power, navigation etc. In view of the huge expenditure involved in such projects, they are only justifiable if the benefits from other developments such as power, irrigation etc., are commensurate.

A plan has also been considered to divert the flood flow of the West River before it reaches the delta. Details have not yet been worked out which would enable a definite conclusion to be formed.

(3) *Soil and Water Conservation*

Soil and water conservation in the upper valley of the three rivers is to be coordinated with other measures to minimize the silt flow of the rivers, and thus prevent the silting of the lower course.

Flood Control Activities

Flood control activities of the Pearl River are chiefly concentrated on the lower course and in the delta. The improvement and maintenance of dikes head the programme. Sluices and regulators have been constructed at the junctions of large creeks with the main river to regulate the inflow into the creeks during floods. A notable example is the one at Lupao, on the eastern bank of the North River, which prevents the excessive flood flow of the creek leading to the city of Canton. Remodelling of the works was carried out after the war to repair heavy damage.

Extensive repairs to dikes were carried out during 1946-1947 after the war, when 3.7 million cu. m. (130 million cu. ft.) of earthwork was completed. Again, after the 1947 flood, total earthwork completed

amounted to 5.8 million cu. m. (204 million cu. ft.). Huge as this quantity of earthwork appears, it is still far below that necessary to bring the dikes to the required cross-section.

RED RIVER

Summary of basic data

Total drainage area	120,000 sq. km.	46,000 sq. mi.
Area of delta	7,000 sq. km.	2,700 sq. mi.
Length of river	1,200 km.	750 mi.
Average annual precipitation (North Viet-Nam) ..	1,800 mm.	72 in.
Maximum discharge at Vietri (estimated for 1945).	35,000 c.m.s.	1,250,000 c.f.s.
Minimum discharge at Hanoi	700 c.m.s.	25,000 c.f.s.
Silt content at Hanoi		
Maximum	0.7 %	
High water average	0.10 %	
Low water average	0.01 %	
Mean annual (1911)	0.082 %	
Annual silt run-off	130,000,000 tons.	

General Features of the River Basin

The Red River (see figure 20) has its source in Yunnan, China, at an elevation of 2,500 m., about 20 km. (12 mi.) south of Ta-Li Lake under the name Yuan River. It has a drainage area of 120,000 sq. km. (46,000 sq. mi.), a total length of 1,200 km. (745 mi.) and is bisected about half way by the Chinese frontier. From Nam Hao to Vietri about 20 rapids occur along its course.

It is only from the beginning of the delta near Vietri that the Red River is joined by two important tributaries — the Black River and the Clear River. The Black also originates in Yunnan, and, flowing parallel to the Red River, has about the same catchment area and a similar river regime to that of the latter. Downstream of Vietri the Red River divides into many branches. On the right bank are the Song Day, the Canal de Nam-Dinh which connects the Red River and the Song Day, and the Song Ninh Co. On the left bank are the Canal des Rapides and the Canal des Bambous, both of which run into the Song Thai Binh. The Song Thai Binh receives the flow of the three rivers, the Song Cau, Song Thuong, Song Luc Nam and serves partly as an extra channel to the sea of the Red River through the Canal des Rapides and the Canal des Bambous. Upstream of the confluence of the Canal des Rapides, the maximum discharge of Song Thai Binh is 4,000 c.m.s. (142,00 c.f.s.).

The delta of North Viet-Nam is formed by the Red River and the Song Thai Binh. It is flat country almost exclusively under paddy cultivation and lies several metres below the level of the highest flood. It is protected by dikes having a total length of 1,400 km. (870 mi.) of which 900 km. are on the Red River delta and the rest 500 km. on the Thai Binh

delta. The area of the delta is approximately 7,000 sq. km. (2,700 sq. mi.) and it is inhabited by 3,500,000 people making a density of 500 per sq. km. (1,300 per sq. mi.). The delta extends about 150 km. (93 mi.) from the sea. Along the winding course on the delta the Red River measures 220 km. (136 mi.).

The delta of North Viet-Nam subject to monsoonal influence, has two distinct seasons, the first from early October to late April which is cool and dry, and coincides with the North-East monsoon, and the second from May to late September which is hot and rainy and coincides with the South-West monsoon.

The monsoons, however, are quite irregular in North Viet-Nam and, therefore, the seasonal limits are ill-defined, while rainfall is irregular. Yearly precipitation at Hanoi, from 1907-1929, varied from 1,274 mm. (50 in.) in 1915 to 2,741 mm. (108 in.) in 1927, which is almost double. The general average during the same period was 1,806 mm. (71 in.).

Eight-tenths of the total precipitation for the year occurs during the months of May, June, July, August and September. Maximum precipitation occurs in August.

Run-off of the Red River depends, not so much on precipitation in the delta itself, but mainly on the precipitation in its basin in Yunnan and the Black River basin, as well as in the high valley of the Clear River.

The rainy season in this high region begins earlier than in North Viet-Nam, but the rapidity and importance of run-off result directly from precipitation accompanying typhoons in the lower part of Yunnan. Heavy precipitation has no other outlet to the sea than through the Red River and the Black River.

When the typhoons occur at long intervals, the run-off of the Red River is negligible. On the contrary,

when they succeed one another at short intervals, water accumulates in the basins of the Red and Black Rivers so that a considerable and lengthy run-off results. Therefore, in the delta of North Viet-Nam, there is no relation between precipitation in the delta itself, and the maximum run-off period. High water period of the Red River lasts generally from 15 June to 15 September. The river remains a threat, however, during July and August. During high water the discharge can be more than 30,000 c.m.s. (1,060,000 c.f.s.) at Vietri. The maximum discharge estimated from flood level was 35,000 c.m.s. (1,250,000 c.f.s.) in 1945.

On an average the flood level at Hanoi remains above (9.5 m.) for one month and over (10.5 m.) for 15 days.

The period of low water flow of the Red River begins from 15 December and ends about 15 May. The minimum discharge occurs from early March to about the middle of April. The average low water level at Hanoi is 2.80 m. with a minimum of 1.95 m. recorded in 1907. The discharge at low water can reach 700 c.m.s. (25,000 c.f.s.) when the water level at Hanoi is 2.00 m. above mean sea level.

The Red River and its effluents continuously transport much clay and silt to the sea, and it is this sediment load that gives the river its characteristic colour.

In the delta a certain amount of scouring takes place, when the velocity of the current reaches 2 to 3 m. per sec. (6.6 to 10 ft. per sec.) during high water. The silt content which, during low water is 100 grammes per cu. m. (0.01 %) by weight, increases from 500 to 1,000 grammes up to 3,000 gms. per cu. m. (3 %) during high water period.

The quantity of clay and silt transported to the sea annually is estimated at 130 million tons, which corresponds to 80 million cu. m. (65,000 ac. ft.). The large amount of sediment load causes considerable silting up at the mouths of the Red River and its effluents, as well as extension of the delta. In the southern part of the delta, in the region of Phat-Diem, this extension seawards is calculated at 10 km. a century in some localities. This accretion of lands is greatly welcomed by villagers along the coast, who construct dikes to protect them from seawater.

Floods and Flood Damage

The Red River delta is protected from floods by earth dikes. These date back several centuries. Since the 13th Century successive rulers of Annam have attempted to establish a central organisation to control a general dike system for the whole of the delta. The probability is that, in the past, the dikes were constructed by private effort, each landlord attempting to protect his own crops and land. This led later to the dike system of the area.

No information is available for flood damage before 1900 but it is known that breaches occurred very frequently such as in the years 1889, 1890, 1893, 1894 and 1899. From the beginning of this century care was taken to strengthen the weakest of the most seriously threatened dikes, but breaches still occurred in 1902, 1903, 1904, 1905, 1911, 1913, 1915, 1917, 1918 and 1926. In 1913 about 30 breaches were registered, in 1915 there were 48 and in 1926 five. Before 1926, on an average, breaches occurred once every three years. The area of inundation was tens of thousands and sometimes hundreds of thousands of hectares. The average annual area of inundation can roughly be estimated at 50,000 ha. (124,000 ac.). Standing crops on half this area would be completely lost as a result of floods. Taking the yield of rice roughly as one ton per hectare, the average annual damage to crops works out at 25,000 tons. Damage to buildings, roads and public utilities can roughly be assessed at 15 per cent of the crop damage. Thus the average annual flood damage, expressed in crops, would be 23,750 tons of rice or roughly two million U.S. dollars.

Flood Problem and Plan of Flood Control

Different measures of flood control have been investigated by the authorities and are here described briefly :

- (1) Reforestation. Reforestation in the headwaters is expected to have a beneficial effect on average floods, but not on exceptional floods which cause most of the actual damage.
- (2) Storage Reservoirs. Investigation of the cost of constructing storage reservoirs in the upper valley has proved that such an undertaking would not be economical.
- (3) Flood Escapes. Flood escapes to divert the flood flow into certain areas, thus relieving the flood stage downstream, have been constructed in Vinh-Yen Province. The possibility exists of diverting the flood flow to some areas near the head of the delta. However, inhabitants of the areas subject to flooding would not willingly agree to such a measure and the proposal consequently has been dropped.
- (4) Improvement of Existing Effluents. It was planned to release part of the flood flow of the main river by increasing the flood discharge of the main effluents, particularly the Day on the right bank and the Canal des Rapides on the left. However, it appears difficult to increase appreciably the flood discharge of the Day. Consideration of the maintenance of the approach channel to Haiphong and other factors also indicate that widening of the Canal des Rapides would not be a satisfactory solution.

- (5) Construction of an Additional Effluent to the Sea. On account of the high maintenance cost, possible silting of the channel and addition of new dikes along the new effluents etc, this proposal is considered unsuitable.
- (6) Removal or Lowering the Level of the Existing Dikes. This proposal was discussed at length during 1895 to 1915. To abolish the dikes and adapt an early rice crop to the flood season is not considered desirable as the yield of early rice is very poor both in quality and quantity. The construction of submersible low dikes to afford protection from early floods, at a height reached approximately by major floods, is not economical.
- (7) Widening of Major Beds. The removal of existing dikes farther away from the river necessitates the construction of new dikes on lower ground. This would be very costly and the reduction of flood-level is very small amounting to a few centimetres for a widening of one kilometre.

The finally adopted plan includes the overall strengthening of the dike system. The programme

was carried out in 1920 and completed in 1944. The standard cross-section adopted for main dikes is :

Minimum top width	7.0 m. (23 ft.)
Height of dike ...	1.3 m. (4.3 ft.) above flood level reaching 12 m. above M.S.L. in Hanoi.
Side slope	1 : 2 (river side) 1 : 3 (land side)

When the dike is more than 5 m. (16.4 ft.) higher than the ground, berms 5 m. (16.4 ft.) wide are provided on the land side of the dike.

The total volume of earthwork over a distance of 1,400 km. (870 mi.), amounts to 120 million cu. m. (157 million cu. yd.) of which 70 million cu. m. (655 million cu yd.) has been completed before 1926 and the rest between 1926 and 1944.

The programme has yielded gratifying results. Since 1926 only one breach occurred, in 1945 during a record flood. This was due largely to unsettled conditions and the lack of efficient supervision of the dikes. It can be said that the Delta is now protected against floods of frequency once in 50 years and that it will probably suffer from a big inundation only once in a century.

SOLO RIVER

General Features of the River Basin

The Solo River (see figure 23) rises from the southern slope of the Lawu in Surakarta Residency. After its joining with the Madiun River near Ngawi, it breaks through the central limestone range. Near Ngluwak it enters the Solo River Valley and finally reaches the sea near Udjung Pangka.

The length of the Solo River is 540 km. (335 mi.) and its total drainage area is 15,000 sq. km. (5,800 sq mi.).

The region which is called the Solo River Valley is bordered in the north by the northern limestone range and in the south by the central limestone range. It is on an average 120 km. (75 mi.) long and 25 km. (15 mi.) wide.

Numerous inundations have raised the area bordering the river, and consequently there is a depression between these raised areas and the hills beyond. This depression must be drained and there are naturally many obstacles impeding free drainage. The lower bowl-shaped area in the eastern part is inundated annually because of inadequate drainage into the sea. In this area, the so-called Bengawan Djero region, about 15,400 ha. (38,000 ac.) of wet and dry fields are flooded.

Another swampy region is situated north of the river and west of Pelangwot. Its area is about 3,400 ha.

(8,400 ac.) of which 225 ha. (540 ac.) or one-fifth comprises wet rice fields.

Flood Control Activities

From ancient times the people have constructed dikes for the purpose of protecting fields from high water. Because of the fear of water shortage during the dry season, the inhabitants have obstructed drainage in some areas.

In 1893 a project was drawn up, the so-called "Old Solo River Valley Project" for providing :

- (1) Irrigation for an area of about 158,000 ha. (390,000 ac.).
- (2) Regulation of the discharge of tributaries of the Solo River.
- (3) Excavation of a new (artificial) Solo River from Pelangwot to Sidajulawas towards the sea, in addition to damming the original Solo River at Pelangwot.

The cost of the work was originally estimated at Florins 19,000,000, but the project involved many difficulties, particularly the excavation of the new Solo River referred to above. To surmount the obstacles, it was expected to cost much more than the originally estimated amount of Florins 19,000,000. Work on the project was therefore suspended.

Plan of Flood Control

The Solo Valley can be divided roughly into the following regions :

Total area	215,000 ha. (530,000 ac.)
Unsuited for agriculture or required for roads, dwelling quarters, etc.	73,000 ha. (180,000 ac.)
Cultivable land	142,000 ha. (350,000 ac.)
Land under technical irriga- tion	17,000 ha. (42,000 ac.)
Land dependent on rain and under marsh	125,000 ha. (308,000 ac.)

From the foregoing it would appear that measures for eliminating floods as well as for developing irrigation are urgently necessary.

Flood control works include :

- (1) Dredging of an artificial flood canal to the sea from Pelangwo to Sidajulawas.
- (2) Construction of buffer basins in the Solo river and its tributaries such as the Pridjetan, Patjal and Gondang rivers which also serve as storage basins for supplying supplementary irrigation water in the dry season. These include :

(a) Pridjetan storage basin.

This project was completed in 1917. The basin has a capacity of about 9,000,000 cu. m. (7,300 ac. ft.) for supplementary irrigation of an area of about 4,700 ha. (11,600 ac.).

(b) Patjal storage basin.

Completed in 1933 the basin has a capacity of 41,000,000 cu. m. (33,200 ac. ft.) for supplementary irrigation of an area of about 16,500 ha. (40,800 ac.) in the dry season.

(c) Gondang storage basin.

Investigations have not yet been completed. The purpose of this basin is to prevent inundation of the Bongawan Djoro region.

(d) Solo River storage basin near Ngawi.

Investigations have not yet been completed. The calculated capacity of this basin is 690 million cu. m. (560,000 ac. ft.) for :

- (i) Irrigation of the Solo Valley comprising an area of 115,000 ha. (284,000 ac.).
- (ii) Generating 19,000 h.p. of hydro-electric power.
- (iii) Navigation.

YANGTZE RIVER

Summary of basic data

Total drainage area	1,830,000 sq.km.	706,000 sq.mi.
Total length of main river	5,590 km.	3,470 mi.
Length of diked section of main river	1,510 km.	937 mi.
Total length of dikes	3,347 km.	2,078 mi.
Main river	2,078 km.	1,290 mi.
Han river	694 km.	431 mi.
Kan river	575 km.	357 mi.
Slope of main river during mean water		
Chungking — Ichang	1:4,970 to 1:20,000	
Ichang — Hankow	1:20,000 to 1:50,000	
Hankow — River mouth	1:50,000 to 1:125,000	
Average annual precipitation over the River Basin	970 mm.	38 in.
Discharge of main river at Chihkiang (1890-1939)		
Maximum discharge (1931)	75,000 c.m.s.	26,500,000 c.f.s.
Mean discharge	16,340 c.m.s.	5,780,000 c.f.s.
Minimum discharge	3,380 c.m.s.	119,000 c.f.s.
Discharge of main river at Tatung (1924-1936)		
Maximum discharge (1931)	80,180 c.m.s.	2,830,000 c.f.s.
Mean discharge	32,490 c.m.s.	1,147,000 c.f.s.
Minimum discharge	5,270 c.m.s.	186,000 c.f.s.
Discharge of Han river at Sianyang (1830-1937)		
Maximum discharge (1935)	35,000 c.m.s.	1,235,000 c.f.s.
Mean discharge	1,200 c.m.s.	42,300 c.f.s.
Minimum discharge	70 c.m.s.	2,400 c.f.s.
Combined maximum discharge of four rivers of Tungting Lake (1926)	62,000 c.m.s.	2,180,000 c.f.s.
Maximum flood volume		
Main river at Chihkiang above 40,000 c.m.s. base flow (1922)	38,200,000,000 cu.m.	31,200,000 ac.ft.
Han river at Sianyang above 15,000 c.m.s. base flow (1935)	4,300,000,000 cu.m.	3,490,000 ac.ft.
Average annual run-off per unit area of main river above Tatung	0.0178 c.m.s./sq.km.	1.63 c.f.s./sq.mi
Maximum silt content of main river	0.561 % (Chihkiang)	0.123 % (Tatung)
Average silt content of main river	0.104 % (Chihkiang)	0.035 % (Tatung)
Minimum silt content of main river	0.0015 % (Chihkiang)	0.008 % (Tatung)
Annual silt run-off at Chihkiang (1937)	967,083,000 tons	
Annual silt run-off at Tatung (1937)	503,651,000 tons	

General features of the River Basin

The Yangtze River, the largest river of this region, has a total length of 5,590 km. (3,470 mi.) and a drainage area of 1,830,000 sq. km. (706,000 sq. mi.), extending from 24°15' N to 36°N latitude and 90°25' E to 122°E longitude.

The river basin (see figure 24) can roughly be divided into two parts. West of 111 1/2°E longitude, it is a mountainous region. The river has its source in the Kunlun mountain with an elevation of 5,150 m. (16,897 ft.). After flowing through successive gorges for a distance of 3,790 km. (2,350 mi.), it debouches on to the alluvial plain at Ichang at an elevation of only 40 m. (131 ft.) above mean sea level. The current is very swift as the river tumbles through rapids and gorges. Fluctuation in the water level is very considerable. The maximum range of the water level at Chungking is 35.75 m. (117 ft.) with a record rise as high as 10 m. (33 ft.) a day during the flood season.

The lower part of the Yangtze basin, east of 111 1/2°E longitude, extends from Ichang to the sea. Its main feature is a vast alluvial plain with numerous lakes dotted along the main water course. The principal tributaries are the four rivers, the Li, Yuan, Tze and Siang, flowing through Tungting Lake, and the Kan River flowing through Po-yang Lake from the south, while the Han River joins the Yangtze at Hankow from the north. On this lower part of the river basin, the Nanling mountain divides the watershed of the Yangtze from that of the Pearl River, while in the north, the Tapch mountain range stands between the Huai and the Yangtze. Below Po-yang Lake, the Yangtze alluvial plain gradually merges with the Huai River plain to form the large Huai — Yangtze Plain of Central China.

The gradient of the lower course of the Yangtze River, stretching for 1,800 km. (1,117 mi.), is very gradual having a slope ranging from 1 : 20,000 to 1 : 125,000 during mean water stage.

The average annual rainfall over the whole basin is about 970 mm. (38 in.). The period from April to August is the wet season with 72 % of the total annual rainfall. Heaviest precipitation occurs in June. The discharge is characterized by the long duration of the mean water flow. The ratio of high to low water is small, amounting to 22 to 1 above Tungting Lake and falling to 15 to 1 around Nanking, because of the detention effect of the lake, which is an important factor governing the flood flow of the lower course of the Yangtze River.

The silt concentration is not high, having a maximum value of only 0.56 % at Chihkiang, but the total annual silt run-off amounts to 967 million tons. Deposition of silt in the lakes along the lower Yangtze River, which reduces considerably their storage capacity, presents a serious problem.

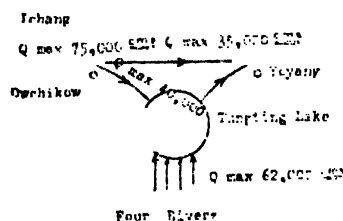
Dikes have been constructed along both banks of the lower course of the main river and its principal

tributaries. Most of the dikes were constructed and maintained by the inhabitants and later the Government took over control. The height of the dikes varies from 3 to 13 m. (9.8 to 42.6 ft.) with free board of 1 m. (3.3 ft.) above the maximum flood level of 1931. The top width is 4 m. (13 ft.) for main dikes and 3 m. (9.8 ft.) for those of the tributaries. The side slope generally is 1 in 2 to 1 in 3 for dikes below 3 m. (9.8 ft.) and a berm with a 1:5 slope is added to dikes higher than 3 m. (9.8 ft.).

The long duration of the mean water flow and the adequate discharge provide very favourable conditions for navigation. A draft of over 8 m. (26 ft.) is available for vessels during high water for a distance of over 1,100 km. (683 mi.) from the river mouth to Hankow. Even during the low water period, vessels with a draft of 1.6 m. (5.2 ft.) can travel 2,830 km. (1,760 mi.) up to Yipin. Numerous waterways, including the Grand Canal, which criss-cross the alluvial plain and join the Yangtze, make this river one of the most important from the transport point of view.

Floods and Flood Damage

The Yangtze River, after leaving the gorge-sections and entering the alluvial plain at Ichang, receives the flow of many important tributaries. Every tributary joining the Yangtze in the alluvial plain has a considerable drainage area. The total drainage areas of the Han and Kan Rivers are 9.6 % and 9.9 % respectively of that of the Yangtze basin, while those of the rivers of Tungting Lake constitute 13.8 % of the whole drainage area. The run-off from the tributaries of the lower course, if it coincides with that of the main river from upstream, results in serious flooding. This condition can best be illustrated in a diagram showing the maximum flood flow of the main river and its tributaries :



At the outlet of the gorge the maximum flood flow of the Yangtze, which corresponds to a frequency of once in 100 years, is 75,000 c.m.s. (2,640,000 c.f.s.). As it reaches the neighbourhood of Owchikow, 40,000 c.m.s. (1,400,000 c.f.s.) of this flow is diverted into the Tungting Lake leaving 35,000 c.m.s. (1,235,000 c.f.s.) to be discharged through the Yangtze proper. The channel of the river from Owchikow to Yoyang, covering a distance of over 100 km. (62 mi.), has a safe channel discharge capacity of only 25,000 c.m.s.

(882,750 c.f.s.). Flooding of this stretch is likely to occur for flows exceeding this value.

Tungting Lake, with an area of 4,670 sq. km. (1,800 sq. mi.) and a capacity of 4,700 million cu. m. (165,957 million cu. ft.) between high and low water, acts as a powerful reservoir, which absorbs the flood flow of the Yangtze and the four rivers running from the south into the lake. The combined maximum discharge of these four rivers is 62,000 c.m.s. (2,180,000 c.f.s.) with a duration of from 7 to 10 days. This usually occurs from the end of May to the beginning of June, and there is frequently a second maximum in August. If the floods of the four rivers coincide with that of the Yangtze proper, and the latter exceeds 60,000 c.m.s. (2,118,000 c.f.s.), the combined flood thus exceeds the detention capacity of the lake, and results in flooding of not only the lake area, but also that along the main river from Owchikow to Yoyang. The situation is deteriorating, since the capacity of Tungting Lake is gradually being reduced by progressive silting, and particularly through illegal reclamation of land during war time by the unauthorized construction of dikes. The annual silt load flowing into Tungting Lake from the Yangtze amounts to 130 million cu. m. (4,590 million cu. ft.), and that from the four rivers amounts to 10 million cu. m. (353 million cu. ft.). The lake area during the war period, as a result, was reduced from 4,700 sq. km. (1,800 sq. mi.) to 3,100 sq. km. (1,190 sq. mi.).

The safe capacity of the Yangtze below Hankow is 67,000 c.m.s. (2,360,000 c.f.s.). The maximum recorded flood flow of the Yangtze below Yoyang, being the combined discharge of the outflow from Tungting Lake and the main river above this junction, is 77,000 c.m.s. (2,710,000 c.f.s.). The occurrence of such a high flood corresponds to once in 100 years frequency and results in breaching of dikes along this section of the river and consequent inundation. The position around and below Hankow is seriously affected further by the flood flow of the Han River. The maximum recorded flood of the Han River is 35,000 c.m.s. (1,235,000 c.f.s.), and the safe channel capacity of the lower course of this river is only 10,000 to 15,000 c.m.s. (353,100 to 529,600 c.f.s.). Serious flooding occurs along the lower Han River during such a flood. Coinciding of floods of the Han and Yangtze would result in tremendous damage to areas along the river below Hankow.

Another main tributary, which joins the Yangtze lower down in the south, is the Kan River with Poyang Lake situated at its outlet to the Yangtze. The safe channel capacity of the lower course of the Yangtze below Poyang Lake is 80,000 c.m.s. (2,820,000 c.f.s.). Flood of the Kan River occurs usually at the end of May. Poyang Lake stores the flood flow of the Kan and releases it gradually into the main river. The simultaneous occurrence of high water flow in the Yangtze and the Kan would result in flooding of this area.

In general, the safe channel capacity of the main river of Yangtze on the alluvial plain in a distance of 1,800 km. (1,120 mi.), is around 65,000 to 80,000 c.m.s. (2,290,000 to 2,820,000 c.f.s.), except in the stretch between Owchikow and Yoyang, where the river flow is partly diverted into Tungting Lake. The channel is capable of discharging the ordinary flood flow of the main river, but is not able to cope with extraordinary floods which occur about once every 100 years. Coinciding of floods of the main river with those of tributaries on its lower course on the vast alluvial plain is not very frequent, though exact statistics about this are not available. Recapitulating Chinese history from 185 B.C. to 1870 A.D. inclusive, a period of 2056 years, serious floods of the Yangtze occurred along its diked section as follows:

From Shashi to Hankow	48 times
Lower course of Han River above Hankow	32 »
From Hankow to Nanking (in the provinces of Anhui and Kiangsi)	12 »
Below Nanking	23 »
Total	115 times

Thus, on the average, serious floods occurred once in every 56 years.

The sole defence against floods is dikes, and their maintenance has an important bearing on flood control. It would appear that flood damage along the Yangtze has become more frequent in the present decade. This can be attributed to the lack of proper maintenance of dikes as a result of the civil disturbances. The gradual silting of lakes such as the Tungting and numerous other small ones along the lower course of the river has reduced their capacity to detain the flood flow. Even more serious is the complete blocking of some lakes for reclamation. A law was enacted by the Government before the war prohibiting the reclamation of lake areas.

A very serious flood of the Yangtze occurred in 1931 when six depressions, during a Mai-U season, travelled along the valley from west to east continuously in June, causing simultaneous flooding of the main river as well as of the tributaries. Diike breaches due to overtopping and side sliding occurred at 33 places along the whole length of the dikes of the main river as well as of the tributaries. The total area inundated amounted to 248,084 sq. km. (95,760 sq. mi.) and 2,527,700 families were affected. The total direct damage was assessed at CNC \$ 1,288,600,000 (prewar values), or the equivalent of US \$ 390,000,000 which is 5.6 % of the total national income, and 9.57 % of the total agricultural income of China for 1931 (1).

The details of the damage of the 1931 flood are given in the following table.

Flood damage of 1931 flood of the Yangtze River

ITEM	DAMAGE IN MILLION \$ CNC OF DIFFERENT PROVINCES						%, OF TOTAL DAMAGE
	HUNAN	HUPEI	KIANGSI	ANHUI	KIANGSU	TOTAL	
<i>Standing crops</i>	118.5	168.7	53.3	187.6	51.6	579.7	45.0
<i>Stored grains</i>	12.7	22.5	4.4	7.9	3.4	50.9	4.0
<i>Farm buildings</i>	54.4	214.2	20.7	39.5	11.2	340.0	26.4
<i>Clothing and furniture</i>	15.7	34.4	7.7	17.8	4.9	80.5	6.3
<i>Farm implements</i>	16.3	30.7	10.5	20.4	2.2	80.1	6.1
<i>Work animals</i>	13.8	33.7	10.1	23.6	2.2	82.4	6.4
<i>Stored fuel</i>	11.1	15.4	4.5	9.8	2.6	43.4	3.4
<i>Domestic livestock</i>	4.2	6.6	2.4	5.6	1.8	20.6	1.6
<i>Stored fodder</i>	1.6	4.6	1.1	2.3	0.4	10.0	0.8
<i>Total</i>	248.3	530.8	114.7	314.5	80.3	1,288.6	100.0

AREA INUNDATED BY FLOODS IN THOUSAND SQ. KM.

<i>Serious</i>	7.33	16.43	26.64	28.08	5.77	82.25
<i>Moderate</i>	32.30	55.72	8.10	34.85	12.10	143.07
<i>Slight</i>	6.77	12.88	—	0.33	0.78	20.76
<i>Total</i>	46.40	85.03	34.74	63.26	18.65	248.08

Another severe flood, not as serious as that of 1931, occurred in the year 1935. The peak discharge then corresponded to a frequency of approximately once in 21 years. The total area damaged amounted to approximately one half of that damaged by the 1931 flood. Damage was estimated at CNC \$ 2,180,000,000 (pre-war value) or US \$ 645,000,000. Average annual damage of the Yangtze floods has been estimated by the Yangtze River Bureau at CNC \$ 100,000,000 or US \$ 30,000,000 for recent years.

Flood Problem and Flood Control Projects

As the numerous lakes along the Yangtze gradually lose their detention capacity, the flood problem becomes correspondingly more serious. The plan for flood control prepared by the Yangtze River Bureau can be summarized as follows:

- (1) Strengthening of river dikes.
- (2) Improvement of condition of the lakes.
- (3) Construction of detention or storage reservoirs.

(1) *Strengthening of dikes.*

As the vast area of Yangtze alluvium, yielding the highest agricultural output in China, relies at present solely on dikes for protection from floods, overall strengthening of the dike system takes precedence over all other means of flood control. After the 1931 flood, all dikes of the Yangtze and its main tributaries covering a total length of 3,347 km. (2,078 mi.) were raised 1 m. (3.28 ft.) higher than the 1931 flood level. A further overall strengthening later is considered necessary.

The possible realigning of the dike system to increase the discharge capacity of the channel during floods, particularly for the stretch from Owchikow to Yoyang and certain other localities for some hundred kilometres, was considered. The problem of resettling the inhabitants of this densely populated area and relocating cities and towns, however, is very important and one that merits careful study.

(2) *Improvement of lakes.*

The combined area of the numerous lakes along the Yangtze is around 17,890 sq. km. (6,900 sq. mi.).

They are connected to the main river and their water level fluctuates with that of the Yangtze. As the larger part of their capacity is absorbed during the mean high water stage, their storage for flood peaks is very slight. Improvement of the lakes, therefore, necessitates control of their in and out flow by regulators. This would reserve their full detention capacity for holding the peak flow of the main river during extraordinary floods. Low dikes, constructed along some shallow areas, will reclaim vast areas of fertile land. The total cost of lake improvement is estimated at CNC \$ 620,000,000 (pre-war value) ⁽¹⁾. Benefits to be derived from such a project from the net profit of the increase of crop yields on reclaimed areas are estimated at CNC \$ 150,000,000 annually.

(3) *Storage and detention projects.*

The strengthening of dikes and improvement of lakes, as calculated by the Yangtze River Bureau, would be sufficient to eliminate the flood flow of a frequency of once in 20 years, such as that of 1935. Further elevation of the existing dikes to hold a maximum flow comparable to that of 1931, i.e., once in 100 years, is not advisable, because in some localities dikes have already attained a height of 13 m. (42.6 ft.) and also because the protection of dikes against extraordinary floods over thousands of kilometres is not considered practicable.

There are many favourable sites along the main river and at the headwaters of the tributaries for the construction of dams. Taking into account the tremendous flood volume of the Yangtze, a high dam to utilize the capacity of the gorge sections of the main river as well as many small dams dotted along the headwaters of the tributaries would provide a solution. The cost of construction of such dams, however, would only be justified if other benefits could be obtained simultaneously, such as water power, irrigation, navigation, etc.

The Yangtze Gorge Plan is the best known one. This plan provides for the construction of a large dam at Ichang, where the Yangtze leaving the gorge, debouches into the alluvial plain. The proposed dam would be 250 m. (833 ft.) high with a capacity of 62,170 million cu. m. (50.3 million ac. ft.). It would be capable of reducing the design maximum flood flow from 93,840 c.m.s. to 43,865 c.m.s. (3,313,490 to 1,548,870 c.f.s.). A huge amount of power would be generated from this single project with an installed capacity of 10,560,000 kw, which could be increased to 14,000,000 kw with upstream storage. The equalizing

of flow of the river downstream of the dam would greatly improve navigation. Irrigation of a vast area is also included in the plan. The cost of the project has been estimated at over US \$ 1,500,000,000.

The land surface of the headwaters is quite well covered with trees and shrubs, and extensive terrace farming is the practice in the red basin of Szechwan. The silt concentration during floods of the Yangtze is only 0.561 % but the annual silt load on account of the large volume of stream run-off reaches 967 million tons at Chihkiang. A reservoir scheme must take into account this 967 million tons or 640 million cu. m. (520,000 ac. ft.) of silt load which constitutes approximately 1 % of the total capacity of the proposed huge reservoir. Soil conservation in the headwaters should, therefore, be included in the project.

The problem of utilizing storage reservoirs to control floods is still being considered. Whether numerous small reservoirs dotted along the headwaters of the tributaries would be more advantageous than a huge single one, especially as regards priority and sequence of development, presents the most important problem to be decided.

Flood Control Activities

The main flood control activities along the Yangtze at present are the maintenance of dikes. A complete strengthening of the dikes along the main river as well as along the tributaries was carried out after the Second World War. The total length of dikes repaired was 2,078 km. (1,290 mi.) for the main river, 694 km. (431 mi.) for the Han River and 575 km. (357 mi.) for the Kan River. Earthwork completed amounted to 62,195,000 cu. m. (2,196,000,000 cu. ft.) ; 2,940,000 cu. m. (103,811,400 cu. ft.) and 3,135,000 cu.m. (110,696,850 cu. ft.) respectively with a total amount of 68,270,000 cu. m. (2,410,613,700 cu. ft.).

Improvement of the lakes was begun before the war at Hua Yang Lake, and was resumed after the war.

Projects of multiple-purpose development were studied during the war, the most notable being the Yangtze Gorge Plan prepared under the supervision of J. L. Savage by a combined staff of Chinese engineers and the Bureau of Reclamation of the U. S. Department of the Interior. Attention has been given to the planning of projects along the tributaries of the main river since the end of the war. A comprehensive plan for the development of the Kan River basin, including flood control, was completed at the end of 1948.

(1) CNC \$ 3.3. = U.S. \$ 1.

YELLOW RIVER (HWANG HO)

Summary of basic data

Total drainage area	771,574 sq. km.	297,828 sq. mi.
Loessial soil area	288,234 sq. km.	111,258 sq. mi.
Length of main river	4,635 km.	2,888 mi.
Length of diked section	700 km.	435 mi.
River slope — River source to Lanchow	1 : 537	
Lanchow to Paotou	1 : 2,140	
Paotou to Lungmen	1 : 1,470	
Lungmen to Mengtsin	1 : 1,520	
Mengtsin to river mouth	1 : 6,375	
Average annual precipitation over river basin from Lanchow to Chenghsien	470 mm.	18.5 in.
Minimum annual precipitation over river basin from Lanchow to Chenghsien	286 mm.	11.3 in.
Maximum flood (1942)	25,000 c.m.s.	333,000 c.f.s.
Average annual discharge } at Shenhsien	1,375 c.m.s.	48,550 c.f.s.
Minimum discharge	245 c.m.s.	8,650 c.f.s.
Maximum flood volume	3,200,000,000 cu. m.	2,590,000 ac. ft.
Maximum run-off	71,201,000,000 cu. m.	57,670,000 ac. ft.
Average annual run-off at Shenhsien	42,991,000,000 cu. m.	34,820,000 ac. ft.
Minimum annual run-off	20,711,000,000 cu. m.	16,720,000 ac. ft.
Average run-off per sq. km. above Shenhsien	0.0019 c.m.s./sq km.	0.174 c.f.s./sq. mi.
Maximum silt content at Shenhsien	46.14 % by weight	
Average silt content at Shenhsien	4.4 % by weight	
Minimum silt content at Shenhsien	less than 0.11 % by weight	
Maximum annual silt run-off	2,643,400,000 tons	
Average annual run-off	1,890,000,000 tons	
Minimum annual silt run-off	686,700,000 tons	

The Yellow River (see figure 25), though not the largest in the region, is certainly the most notorious for its floods and shifting of its course, which has occurred six times over a recorded history of 4,000 years. This number does not include shiftings such as the most recent one in 1938, when the river followed a new course for a period of only a few years. The heavy silt load of the main river, which reaches 46 percent by weight during the flood season, and the deposition of silt between the dikes, which has raised the mean river bed higher than the adjacent land, is a unique phenomenon in the region. The Yellow River, also known as «China's Sorrow», presents a flood problem which has been tackled for thousands of years, and still awaits solution. It deserves a more detailed description.

General Features of the River Basin

The catchment area of the Yellow River basin extends from longitude 95 1/2°E to 118 1/2°E and from latitude 32 1/2°N to 40°N. It is in an arid and

semi-arid region with an average annual precipitation varying from 150 to 750 mm. (6 to 30 in.). The general topography of the river basin lends itself into a rough division into two parts, the great alluvial plain with 600 km. (373 mi.) of continuous dikes on the east, and the partly loess-covered hilly plateau on the west. As one travels along the great plain westward from the sea, hilly plateaus rise abruptly from the plain with a sudden increase in elevation of about 1,000 m. (3,300 ft.).

The catchment area of the whole drainage basin is 771,574 sq. km. (297,828 sq. mi.). As the river in the plain is confined by two parallel dikes, its catchment area there is only 14,880 sq. km. (5,720 sq. mi.) or 1.9 per cent of the total. Of the vast drainage area of the hilly plateau, 38 per cent or 288,234 sq. km. (111,258 sq. mi.) is well covered with a chestnut-coloured soil known as "loess". This is a wind-blown deposit from Siberia, some 15,000 to 40,000 years old, which covers the hilly plateaus of Shansi, Shensi and eastern Kansu provinces to an average depth of 50 m. (165 ft.). Loess is uniform in its composition, fragile in texture, with particles

ranging from 0.001 to 0.2 mm. in diameter. Soil erosion during rain storms is very severe. The stream flow is a muddy paste with a maximum silt content as high as per cent by weight (weight of dry silt per unit weight of suspension). As the river debouches into the great plain, a reduction of velocity results in tremendous deposition. There is no doubt that the great plain has been built up by the silt-laden flow itself, and there is evidence to prove that the shoreline is being gradually extended seaward.

The Yellow River has its ultimate source in Singu Hai (lake), Tsinghai Province, at an elevation of about 4,350 m. (14,400 ft.) above sea level. From the source to Ninghsia at an elevation of 1,091 m. (3,580 ft.) above mean sea level, and a distance of about 2,007 km. (1,247 mi.), the river flows generally in narrow reaches confined by rocky hills which are partly covered with loess. The incision of the river bed is still continuing, judging from the old terraces and river banks. Broad valleys are formed above such places where the river cuts across a mountain ridge. Looking at the map, these are usually places where large cities are located such as Lanchow, or Chungwei. The width of the Yellow River along this section varies from 100 to 400 m. (330 to 1,300 ft.). Its depth varies from 1 to 9 m. (3 to 30 ft.), and its velocity from 1.5 to 4 m. per sec. (5 to 13 ft. per sec.). Navigation is, at present, limited to skin rafts for downstream trips.

Below Ninghsia, the Yellow River makes a large loop, or a semicircle, enclosing the area which is known as the Ordos. The whole region is a flat plateau covered with silty brown earth with an elevation of around 1,000 m. (3,280 ft.) above sea level. Irrigation along the Yellow River, on the north side, by gravity flow, is quite extensive.

From Hochu to Lungmen, the river flows southward in a narrow gorge section. The Wei River system of the Shensi plain joins the Yellow River at Tungkwan, where the latter turns eastward, passing through another narrow gorge till it reaches Mengtsin, and then debouches into the great alluvial plain.

Viewing the general topography of the great plain one may consider Mengtsin to be the apex of the vast alluvial cone. The Yellow River, flowing on this alluvial cone, is confined on both sides continuously by dikes, except for a short distance at the foot of the Tai Mountain. The distance between the dikes varies from 20 km. (13 mi.) in the vicinity of Kaifeng to 1.5 km. (1 mi.) as it reaches the sea coast. Constant deposition of the heavy silt load during the flood season has raised the river bed between the dikes to an elevation of not less than 4 m. (13 ft.) above the adjacent land, thus making the Yellow River flow high up on a ridge and become a watershed dividing line of the great plain. A section drawn across the river plain at a distance 450 km. from the river mouth, as shown in Fig. 25, clearly illustrates this phenomenon.

The dikes are built of sandy loam, material deposited by the river itself, and, at some places, are protected by a facing of sorghum stalks. Stone is scarce, and is only used at critical sections. The height of the dikes varies from 3 to 13 m. (10 to 43 ft.), with a top width of 10 to 20 m. (33 to 66 ft.), and side slopes of 1:2 to 1:3.

Fluctuation of the water level of the lower course from high to low is around 6 m. (20 ft.). During low water seasons, the channel splits up into branches and the width of the water surface varies from 400 to 2,000 m. (1,300 to 6,500 ft.). Navigation is possible for junks, except during winter, when the river is blocked by floating ice.

The annual precipitation, in general, varies from 750 mm. (30 in.) in the south-east to 150 mm. (59 in.) in Ordos. June to August are the rainiest months of the year and, during them, at most places, 70 % or more of the yearly total falls. Because of the summer rainfall, and the varying strength of the summer monsoon from year to year, the annual and monthly variability of precipitation is considerable. The annual variability amounts to 100 to 150 per cent and the ratio of maximum to minimum rainfall for the rainiest month is 7 to 1. This great variability has caused droughts and floods of the basin.

The fluctuation of the river flow follows, in general, the pattern of rainfall fluctuation, as there are practically no lakes or reservoirs of significant capacity to modify the flow. The flood season is reckoned from July to October inclusive, corresponding to the rainy season, while low water is from late October to early June, which is the dry season of the basin. The total run-off of the flood season, July to October, amounts on the average to more than 60 per cent of the annual run-off. The winter flow is chiefly maintained by ground water discharge, while the spring flow is supplemented by the melting of snow.

The Yellow River and its tributaries flow mostly in loessial areas from which the river derives its high silt content. Most of the areas receiving summer showers are composed of bare loessial soil of high erosive potential, and with moderate slopes. In some localities the water-absorbing prairies and woodlands have been replaced by cultivated fields which have further accelerated the rate of soil erosion, and increased the silt flow of the stream. Since factors affecting run-off are the same as those affecting erosion, the silt flow follows the general pattern of run-off. Suspension samples are taken at different stations. The silt content, during low water season, is below 1 per cent by weight, while during the flood season the record at Shenhhsien shows a silt content as high as 46 per cent. The mean annual silt run-off is 1,890 millions tons, and the maximum reaches 2,643 million tons. Of the total annual silt run-off, 80 per cent appears in the three months of the flood season from August to October.

Floods and Flood Damage

There are so called "four flood periods" in the Yellow River, namely the spring, summer, autumn and winter floods. The spring flood, indicated by a sudden rise of river stage in the lower course of the river over a period of not more than 10 days, due to the melting of snow, is not very dangerous, because of its comparatively small discharge and short duration. The winter or ice flood, caused by a piling up of ice blocks which induce a rise of water level and overtopping of dikes, similarly is not very serious as the river discharge is small. By far the more grave are the summer and autumn floods during the maximum discharge of the year.

Summer or autumn floods, which originate above the Ordos loop, such as at Lanchow, are greatly reduced in magnitude as they reach the lower course of the river owing to channel storage. An analysis of flood data indicates that the major floods are solely the result of precipitation over the fan-shaped Wei River system, or the fishbone-shaped drainage area along the gorge section below Ordos to Lungmen.

The recorded maximum flood peak at Shenhshien is 25,000 c.m.s. (883,000 c.f.s.), and the corresponding flood volume is 1,810 million cu.m. (1.47 million ac.ft.). Both flood peak and flood volume are small as compared with those of other major rivers of the region. It is not the flood discharge alone that governs the flood problem of the Yellow River, but also the heavy silt content of the latter which aggravates the position. Constant deposition of silt load on the river bed necessitates progressive raising of the height of the dikes. Moreover, the highly erodible fine silt of the river bed is very unstable in the current. With the main dikes spaced at distances of 1 to 20 km. (.6 to 12.5 mi.) apart, the main current of flood flow does not spread evenly over the entire section, but swings and changes its course within the wide channel. This frequently-changing current attacks the dikes at unexpected locations, thus complicating the problem

of defence. Since earth dikes built of fine silt are generally not strong enough to withstand the wash of current, breaches occur frequently. As the lower course of the river is running on a ridge a few metres higher than the adjacent land, the flood flow from the breach diverts almost completely from the main course. Closure work can only be performed when the flood season is over. If closure work fails successively for years, a shifting of river course naturally follows. Tracing back Chinese history, it will be seen that the Yellow River has shifted its course six times. Its outlet once reached the Hai River (near Tientsin) in the north and the Yangtze River (between Nanking and Shanghai) in the south, a distance of over 600 km. (370 mi.). Fig. 25 shows the changes of course as recorded in Chinese history.

Statistics of dike breach occurrences can be traced back in China's history to 359 B. C. In general, shifting of the river's course and the occurrence of dike breaches clearly reflect the internal situation in China at that time. During periods of internal peace and prosperity, when large sums were available for the repair and maintenance of dikes, breaches occurred at less frequent intervals. On the other hand, a shifting of the river's course, usually due to neglect in completing dike closure works, generally took place during changes of dynasty, or when troubled conditions prevailed.

The magnitude of the flood discharge has a very definite bearing on dike breaches. Correlation of records of flood discharges and dike breaches from 1919 to 1938, when the Yellow River was flowing on the present course, shows clearly this relation as tabulated below: Though the record does not cover a sufficiently long period for any definite conclusions to be drawn, an analysis shows the general tendency that, with a river discharge below 3,000 c.m.s., no breach is likely to occur, while with a discharge greater than 12,000 cubic c.m.s. dike breaches are almost certain. Sufficient and effective dike maintenance can certainly change the limits mentioned above, and remedy the situation.

Probability of dike breach occurrence of the Yellow River 1919 to 1938

PEAK DISCHARGE OF FLOODS C. M. S.	MEAN VALUE C. M. S.	NO OF PEAK DISCHARGE OCCURRENCE	NO OF DIKE BREACH OCCURRENCE	PROBABILITY OF DIKE BREACH OCCURRENCE %	PROBABILITY OF PEAK DISCHARGE OCCURRENCE %
2,000 — 4,000	3,000	87	2	2.3	97.5
4,000 — 6,000	5,000	43	2	4.65	81.0
6,000 — 8,000	7,000	17	2	11.7	59.5
8,000 — 10,000	9,000	9	3	33.3	39.5
10,000 — 14,000	12,000	1	1	100.0	20.0

Based on statistics, dike breaches of the Yellow River, occurred 51 times since it took its present course, over a period of 83 years from 1855-1938. The frequency of dike breaches reached as high as 60.7 % which is more than once every two years. The flood waters ran into a more or less definite region following the location of the breaches and the topography.

The total area inundated during this period, was worked out as 194,680 sq. km. (75,000 sq. mi.), or an average annual inundated area of 2,318 sq. km. (900 sq. mi.).

Records of unit damage of the flooded area, based on actual surveys which are available since the 1926 flood, are given in the table below. The figures of

flood damage are rated at pre-war values and indicate direct damage such as crop losses, livestock and farm implement losses, damage to buildings and public utilities. Indirect losses are not included.

Flood damage of the Yellow River

YEAR	FLOOD AREA SQ. KM.	FLOOD DAMAGE MILLION \$ C. N. C.	UNIT DAMAGE C. N. C. \$ PER SQ. K. M.	UNIT DAMAGE U. S. \$ PER SQ. KM. (a)
1926	2,408	20	9,750	2,930
1933	11,650	266	22,850	6,850
1934	3,150	120	38,100	11,420
1935	10,000	267	26,700	8,010
1938	24,600	286.9	11,620	3,480
AVERAGE			21,804	6,538

(a) U.S. \$ 1 = C.N.C. \$ 3.33 (1937).

The average annual area of inundation, calculated over a period of 83 years, is 2,318 sq. km. with an average unit damage of C.N.C. \$ 21,804 or U.S. \$ 6,538, per square kilometre. The average annual flood damage of the Yellow River thus amounts to C.N.C. \$ 50,500,000 or U.S. \$ 15,000,000. Since the area damaged by floods is farm land with an average density of population of 395 per square kilometre, the average annual population affected by floods is approximately 900,000. This is a serious problem in China.

Flood Problem and Proposed Plan of Flood Control

Numerous Chinese scholars and officials in charge of flood control have studied all possible ways of controlling the Yellow River, since its first recorded flood in 2297 B.C., and in recent years many European and American engineers have suggested measures to regulate it. Various engineering plans for regulation of the lower Yellow River and storage of flood in the upper reaches have also been prepared by flood control authorities.

The classical approach to the problem follows the tradition of river training. There is no doubt that the tremendous silt deposition, by raising the river bed between dikes, seriously aggravates the flood situation. With the existing flood discharge and silt load as a given condition, the idea behind training the lower course of the Yellow River is to so regulate its flow that ultimately the river bed is scoured below the adjacent ground surface. Then the Yellow River will no longer flow high up on a ridge of the great alluvial plain. In this connection the proposal of C. H. Pan (1512-1595), the famous engineer, is worthy of mention. Pan proposed confining the flow of the lower course of the Yellow River within a narrow channel by two parallel "Louti" or near dikes for downscouring of the river bed, and another system of "Yaoti"

or far dikes to provide sufficient space for flood storage, besides acting as a second line of defence.

H. Engels, commissioned by the Chinese Government, conducted two large-scale model tests for the Yellow River in 1932 and 1934, and suggested stabilization of the mean water bed to train the lower Yellow River. Following up the idea of river training, the Yellow River Commission in 1946 prepared a comprehensive plan to regulate the course of the river with a system of permeable and solid spur dikes and training walls, with the ultimate aim of scouring the channel bed down below ground level. The maximum design flood flow is 28,000 c.m.s. (990,000 c.f.s.) of which 24,000 c.m.s. (850,000 c.f.s.) is to be discharged by the lower course, and the balance dealt with by diversion or detention. The designed river bed takes the form of a double profile with a well-defined parabola-shaped channel and wide fore-shores between the channel and the dikes. The width of the channel is 500 m. (1640 ft.) and the average depth varies from 5.97 to 10.90 m. (19.7 to 35.8 ft.). The width of the foreshore varies from 1,500 m. to 11,850 m. (4,900 to 39,000 ft.) with an average depth over the foreshore from 1.25 m. to 2.5 m. (4.1 to 8.2 ft.). The slope of the channel varies from 1 : 1,010 to 1 : 10,000. Permeable or solid spur dikes and silt arresting dikes are to be constructed on the foreshore to guide the flow in the channel with the object of obtaining a scouring of the channel bed. The vast area of the foreshore acts as a kind of flood storage basin, resembling a lake, to absorb the flood peak as well as for silt storage. Improvements of alignment and cross-section of existing dikes are included in the proposal. The total cost of such a regulation plan would be in the neighbourhood of C.N.C. \$ 300 million (pre-war value), or around U.S. \$ 100 million.

The idea of detaining or storing the flood flow of the Yellow River in its upper reaches has long been debated by different authorities. Many good dam sites with sufficient storage capacity are available along the upper course as well as along the tributaries of the Yellow River. In view of the short duration of flood flow (5 to 7 days) and the comparatively small flood volume (3,000 million cu. m. or 2.43 million ac. ft.), flood control by storage or detention would certainly be a very effective and dependable measure, but the problem is greatly complicated by the heavy silt load present in the flood flow of the river. The maximum silt concentration is 46 per cent by weight and the annual silt run-off reaches 1,890 million tons. From 1939 to 1944 the Oriental Research Institute of Japan conducted an exhaustive study of the problem and recommended the construction of a series of dams in the upper reaches of the main river — for power development and flood control. Moveable gates were proposed on the crest of one of the main dams at Samen to store a part of the flood, when the storage below the crest is filled up. The reduced flood flow (from 30,000 to 20,000 c.m.s.), when discharging into

the lower course, will be further reduced by channel storage (20,000 to 14,000 c.m.s.) and will ultimately be diverted into two channels (9,000 and 5,000 c.m.s.) and thence to the sea.

In 1946 a Yellow River Consulting Board was organized under the Public Works Commission consisting of three engineers — J. L. Savage, E. Reybold and J. P. Growdon. This Board recommended the construction of a "gorge type" reservoir at Palihutung just above the river plain with a 170 m. (560 ft.) high dam to regulate the flood flow and a reasonably straight channel to discharge the regulated flow to the sea. It is estimated that, with a "gorge type" reservoir having large capacity outlets at the bottom of the dam, half the reservoir capacity can be permanently retained for flood detention by proper operation. The channel from the reservoir to the sea on the alluvial plain should be designed to carry the flood waters at the maximum rate at which they are released from the reservoir at a controlled maximum silt content of 20 per cent without causing deposition. However, how excessive deposition in the reservoir can be avoided, and how the out-flowing silt load can be regulated still remain to be solved. The cost of constructing such a dam at Palihutung, generating 400,000 kw. of firm power, as prepared by the Public Works Commission, would be around U.S. \$ 117 million. As the silting of reservoirs is a serious problem which must be faced, the construction of such a reservoir does not appear to be justified without previous solution of the silt problem. Intensive research on silting and desilting of reservoirs is being carried out in China.

In view of the comparatively small flood volume, but enormous silt load, it can be concluded with justification that Yellow River flood control is a problem more of silt than of water. The importance of soil conservation on the vast loessial area, where "China's Sorrow" originates, has long attracted attention. Sheet and gully erosion is everywhere serious and bank-caving also contributes to a considerable amount of erosion. On account of the dense population, steep slopes over 45 degrees are cultivated for food production with the planting season during the period of summer precipitation. For the purpose of soil conservation, however, these slopes should rightly be reserved for pastures. In winter, bushes and grass are dug up, roots and all, to provide fuel. Probably the reason why farmers completely neglect soil conservation work is that the 50 metres deep loess is itself fertile to the last centimetre of soil. The problem is not so much one of discovering a soil conservation method which would be technically feasible, such as grassing, but to work out a technical and economic method on the conserved soil of the small plot of the farmer to step up food production to a level that would enable him to support his family. The vastness of the loessial area is, at present, another factor in this problem. Only such methods as would

increase the yield of foodstuffs or other cash crops in a comparatively short period would appeal to farmers of such a wide area.

Experimental work on soil and water conservation is being carried out at several stations in the loessial region, and experimental gully dams have been constructed in many places. The period of experiment is still too short to give a definite answer.

Since 1946, various agencies have cooperated to tackle the problem as a whole embracing flood control, irrigation, reclamation, power development, navigation, land improvement and soil and water conservation. The task is to determine the most appropriate and economical combination of the various methods to obtain the best results. Various schemes have been drawn up to compare costs and benefits. Planning work for ultimate development of the basin has not yet been completed. A study of the priority of different phases of development indicates the paramount importance of flood control, with irrigation and reclamation, water power development and navigation following in that order. Regarding the sequence of development, the study completed so far emphasizes, firstly, the immediate necessity for strengthening existing dikes and dike protection works and the initiation of soil and water conservation. River training and flood storage and detention should be carried out in small tributaries to gain experience of silting problems, before an attempt is made to carry out major remedies on the main river.

Flood Control Activities

The main activities concerning the Yellow River, consist mainly of: —

- (1) The annual maintenance of 1,200 km. of main dikes.
- (2) Preparation of the final development scheme.
- (3) Research on the silt problem.

The dike closure works carried out during 1945-1946 to turn the river back into its old course is worthy of mention. The river changed its course in 1938, during the war at Hwayuankuo, flowing into the Huai River and finally into the Yangtze River. The old bed of the Yellow River, below the breach, was gradually silted up with the flow completely diverted to the new course. Dike closure work was carried out in 1945 after the war. The low water flow during closure was around 2,000 c.m.s. (70,000 c.f.s.). By dumping loose rock in wire cages from a wooden trestle bridge 400 m. (1,300 ft.) long built across the new course of the river, the water level was gradually raised to a height of around 4 m. (13 ft.) and the river diverted to its old course. The construction takes the form of a rock-filled overflow dam with willow mattresses at the bottom. A series of canals were excavated on the river bed of the old course to facilitate the flow. The closure work was completed with UNRRA aid in 1946.

SYMBOLS EMPLOYED

...	not available	—	nil or negligible
mm.	millimetres	in.	inches
cm.	centimetres	ft.	feet
m.	metres	mi.	miles
km.	kilometres	sq.mi.	square miles
sq.km.	square kilometres	ac.	acres
ha.	hectares	cu.ft.	cubic feet
cu.m.	cubic metres	ac.ft.	acre feet
mil.cu.m.	million cubic metres	m.ac.ft.	million acre feet
c.m.s.	cubic metres per second	c.f.s.	cubic feet per second
t.	metric tons	hp.	horse-powers
kw	kilowatts		
C.N.C.	Chinese national currency		
P.	Peso (Philippines)		
Rs.	Rupees (Burma, Ceylon, India and Pakistan)		

SIMPLE CONVERSION TABLE

1 mm.	= 0.039,4	in.	1 in.	= 25.4	mm.
1 m.	= 3.281	ft.	1 ft.	= 0.304,8	m.
1 km.	= 0.621,4	mi.	1 mi.	= 1.609,3	km.
1 sq.km.	= 0.386,1	sq.mi.	1 sq.mi.	= 2.590	sq.km.
1 ha.	= 2.471	ac.	1 ac.	= 0.404,7	ha.
1 cu.m.	= 35.31	cu.ft.	1 cu.ft.	= 0.028,32	cu.m.
1 cu.m.	= 0.000,810,3	ac.ft.	1 ac.ft.	= 1,234	cu.m.

नसरी

यह पुस्तक निम्नांकित तारीख तक वापिस करनी है ।

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